A TIME SERIES ANALYSIS OF THE CRUDE OIL SPOT AND FUTURES MARKETS

By

JING QUAN

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN
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I dedicate this dissertation to the faculty of the Department of Economics at the University of Florida.

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This dissertation studies the spot and futures markets for crude oil. Its main objective is to study the relationship between these two markets, in particular, the role of crude oil futures market in the working of the spot market. A contribution of this dissertation is to provide a better understanding of the crude oil markets. In order to investigate the relationship between the two markets, a two-stage testing procedure is proposed in this study. First, the existence of any long-run relationship is tested using cointegration tests. Second, Granger causality tests and Garbade and Silber approach are applied to determine the direction of causality.

The first relationship investigated in this study is between the crude oil spot and futures prices. This is known as the "price discovery" role of futures prices. Different assumptions about the futures market lead to different conclusions. For example, the random walk hypothesis states

that futures prices do not provide information on the spot price. The market efficiency hypothesis, on the other hand, assumes the opposite conclusion. These two hypotheses are tested in this dissertation. It is found that spot price leads futures prices instead of the futures price providing information on the spot price. Therefore, the hypothesis that the futures prices have a price discovery role is rejected.

Two additional relationships to be studied are those between the OPEC oil supply and the futures prices and that between the same supply and spot prices. The hypotheses that there are co-integration relationships between the variables are rejected for both cases. In the case of OPEC supply and spot prices, a "self-adaptive" model with supply interruption dummy variables is introduced to study the price behavior. It is found that prices follow an adaptive process, that is, the previous price information offers powerful influence on the current price.

CHAPTER I
INTRODUCTION

The dramatic developments in the world oil markets over the past two decades have had far-reaching effects on the world economy. Two oil price shocks and one price collapse exerted a powerful influence on the global economy and on international relations. Ramifications can be seen in two world recessions, in the third world debt problems, in attempts to resolve Arab-Israeli differences, in the expansion of the U.S. military role in the Persian Gulf, and in the virulent boom and bust cycles in oil producing countries and in the major oil producing regions in the United States. The relationship between oil and a country's economy has proved to be very significant.

Needless to say, the most significant event in the history of the oil market over the last twenty years was the emergence of the Organization of Petroleum Exporting Countries (OPEC), which has become the major force in determining the price of crude oil and the production policies of its members. In addition, it has revolutionized the contractual relationship with the international oil companies. As a result, the traditional role of the major international oil

companies as the sole force in the activities in the world petroleum market (exploration, production, transportation, refining, and marketing) has changed. The domestic pricing and energy resource development policies of oil-importing countries as well as their energy consumption patterns have also changed. Massive transfers of wealth from the major industrial countries to the OPEC member countries have occurred. Concern over balance-of-payment deficits and recycling of oil money back to the economies of the industrial countries has intensified. New economic relationships are emerging between the developed industrial countries, OPEC member countries, and other less developed countries. These new relationships have been accompanied by a new era of international diplomacy.

Obviously, energy is one of the foundations on which our civilization rests, and one for which there is no substitute. The connection between the consumption of primary energy carriers and economic development is unmistakable. At present petroleum is the world's main energy carrier. Forecasts of future crude oil prices, crude oil availability, OPEC's stability, and its price and production strategies all affect the decisions of oil-importing countries with respect to developing alternative and costlier energy resources. To appreciate the relationship between oil and the economy, let us examine in greater detail the relationship between oil and some key macroeconomic variables.

Oil and energy's economic value and volatility in the world economy is a good place to begin. At today's prices, the value of primary energy production amounts to about 4.5 percent of the world economic output, with oil accounting for almost half of the total value. That makes energy production worth three times the value of all food grain production (rice, wheat, and coarse grains). A similar picture emerges in world trade. Oil exporters alone account for about 6 percent of total world exports and are almost five times as large as the value of all food grain exports. Even more important is the volatility of oil's value. In 1970, when oil was still comparatively cheap and consumption growing rapidly, primary energy output was equal to 1.7 percent of world GNP and oil less than 1.0 percent. In 1981, when the price of oil reached its peak, energy production constituted 10 percent, and oil 6 percent, of world output. Swings of this magnitude in the space of a decade necessarily set in motion vast structural changes throughout the world economy.

A second key macroeconomic variable associated with oil is inflation. Of course, there are many factors in determining the inflation rate--the monetary policy and willingness to trade inflation against unemployment. However, one also has to admit that the increase in oil price is one the most important factors. Since oil is an input in most industrial processes, either directly or indirectly, and plays a prominent role in some of the most important consumer activities such as driving

and heating, it would be difficult to argue that the 850-percent increase in the price of oil between October 1973 and January 1981 was not a major factor in raising the general price level. It was not only major, but crucial. Prior to the first oil shock, world prices were increasing at a rate of 6 percent annually, and this was regarded as an aberration that would soon be brought under control. Today double-digit inflation is common in many countries, and it is not expected to be brought down to rates below the 1973 levels in the near future.

Take the United States' economy during the period 1973-1979 as an example. Following the oil-price shock of 1973-1974, prices in the United States increased by enough to restore the quasi-rents of capital goods to their 1972-1973 levels. With only marginal increase in money wages, real wages fell by enough to pay the increased oil bill. Moreover, oil imports increased by a very large amount, which removed any barriers to the expansion of production that might have resulted from the physical unavailability of energy. It also happened that inflation and the depreciation of the dollar prevented the real price of oil from rising in the face of some minor upward adjustments of the money price of oil. By 1977, the United States had more or less recovered from the first oil-price shock. Both employment and output were increasing at a satisfactory rate, especially output; the principal difference between the economy in 1977-1978 and that

in 1972-1973 was that prices moved up faster after 1973. The latest example in the United States can also confirm the relationship between oil price and inflation. Consumer price index in the United States rose 0.4 percent in December 1989, for the year, it reached 4.6 percent, the highest since 1981. The Federal Reserve seems much concerned about fighting the upcoming inflation. One of the biggest reasons behind the rise in the consumer price index was higher fuel prices resulting from December's freeze. The impact for January 1990 should be even more evident.

The fear of inflation strongly influences the performance of the stock market. For instance, The biggest selloff in the New York stock market since the October 1989 "mini-crash" hit the stock market on Friday, January 12, 1990. The Dow Jones average of 30 industrial tumbled 71.46 points to 2,689.21, the its largest loss since it plunged 190.58 in October 1989. One of the major causes were the new inflation worries. The Department of Labor reported that the producer price index of finished goods rose 0.7 percent in December, exceeding advance estimates for that measure of inflationary pressures. The index finished 1989 with an increase of 4.8 percent, its biggest in eight years.

Finally, it should be mentioned that the oil-price shock initiated by OPEC helps some industrial countries--those which possess energy resources themselves. The sharp rise in oil prices has increased the value of Australian coal, gas and

uranium reserves and has contributed to England's ability to generate foreign exchange.

From the above discussion, one can easily appreciate the importance of the world oil market. However, since there are two kinds of markets for oil, namely, the spot market and futures market, in order to understand the oil markets, it is necessary to study both these markets, and the relationships between them.

The spot, or cash, market need not be a market in the institutional sense of the word, but simply an arrangement between buyers and sellers that calls for delivery--though perhaps not consumption--of a commodity in the immediate future. In the case of oil, the Rotterdam Spot Market has literally become a household term; but although it is true that this district of Holland is blessed with extensive brokerage and oil-storage facilities, it bears only a passing resemblance to the conventional image of a market, since there is no physical locale, and trading takes place by means of telecommunications. Similarly, the spot or cash price pertains to the immediate transfer of ownership of a commodity.

To assess the course of the spot market in oil, it is helpful to review its recent history. After rising sharply during the 1970s, the price of oil peaked at $37 a barrel in 1981, declined steadily thereafter to $27 a barrel by 1985, and then plummeted to $14 a barrel in 1986. Although the price rose somewhat in 1987, it still was far below the levels of

the early 1980s. Indeed, after adjustment for inflation, the October 1987 price was below the price reached after the first oil shock of 1973-74.

The futures market is an arrangement that features paper transactions. Physical delivery of the commodity occurs in only a small minority of cases. Strictly speaking, a futures contract is a forward contract in that these contracts almost always refer to a particular month of delivery; at the same time, however, a futures market is so organized that sales or purchases can be offset, and the deliveries are unnecessary. In addition, futures contracts are bought and sold through an exchange, impersonally, with the validity of contracts guaranteed by the exchange. In order for this type of market to function smoothly, large numbers of traders are required --in particular speculators, who play a major role in generating the flow of contracts that permit other types of market actors (such as sellers and purchasers of physical commodities like oil) to avoid price risk. It should be made clear that these speculators, who are uninterested in the physical commodity, but have distinct ideas about the price of oil in the future, are buying or selling contracts with the intention of making an offsetting sale or purchase later. If, for example, the offsetting purchase price is less than that of the original sale, the speculators will make a profit.

There are many factors interacting in the oil markets, such as spot prices, futures prices, world supply, world

demand, the weather influence, and so on. In this thesis, three important relationships will be studied: that between futures prices and spot prices--to test the role of crude oil futures prices in price discovery; that between futures prices and OPEC supply--to test the role of OPEC supply in the formation of expectation for the price of the futures; and finally, that between the spot prices and OPEC supply--to test the influences of sudden supply shocks in the prices.

The relationship between the futures price and spot price for the deliverable good at the maturity of the futures contract is one of the long-standing research issues. It is an important question, since its resolution has important implications for futures market speculation, for the efficiency of the futures market, and for the effective implementation of futures market hedges. The relationship between the futures price and supply has not been paid much attention before. However, it is important. Undoubtedly, in futures markets, traders speculate on the supply available in the near future and determine how much they are willing-to-pay for the commodity. The oil market has long been a sellers' market. Traders' expectation of future prices depends heavily on the their expectations of future production. It is observed that once after the annual meeting of OPEC member countries set up the new quota, the crude oil futures prices will respond instantaneously. The relationship between spot price and supply is obvious. Unanticipated supply shock theory can

be applied to the oil market. All "oil crises" in the past were due to supply shocks. The spot prices respond almost immediately to the supply. The opposite direction is also true. When the price drops below a certain point, OPEC will interrupt the price slide by reducing the supply and attempt to make the price rebounce.

The rest of the thesis is organized as follows. Chapter II studies the relationship between the futures price and spot price. The relationship between the futures price and OPEC supply is investigated in Chapter III. Chapter IV examines the relationship between the spot price and OPEC supply. And finally, the conclusions are summarized in Chapter V.

CHAPTER II
SPOT PRICES AND FUTURES PRICES:
THE PRICE DISCOVERY OF CRUDE OIL FUTURES PRICES

Introduction

Futures prices reflect the opinions of producers, consumers and speculators about the prices of different commodities in the markets at a later date. To be of value to hedgers, the futures price must respond quickly and accurately to relevant new information. The ability of a futures market to process information has been investigated by many researchers. The following two hypotheses have been the focus of their study: random walk and market efficiency.

The random walk hypothesis states that the most accurate forecast of the next period price is today's price. There is then no correlation between the price changes on different days, and no information in past prices is useful for forecasting future prices. Working (1934) and Kendall (1953) recognized that the behavior of prices is very similar to random walk. This suggests that speculators cannot use the information in present and past prices to trade profitably. This conclusion leads to one of the definitions of the efficient market hypothesis (Jensen, 1978). The so-called linear process has been assumed in nearly all the tests. Many ways to test the random walk hypothesis have been proposed.

In the early 1970s papers by Stevenson and Bear (1970), Leuthold (1972) and Cargill and Rausser (1975), however, claimed that futures prices did not exactly follow a random walk, which implied that some information took more than one day to be absorbed correctly into the prices. The efficient market hypothesis can be true when the random walk hypothesis is invalid, provided that trading costs prevent a complete exploitation of the information reflected relatively slowly in the prices. An efficient market processes information fairly, which means that the information can be equally easily accessed by different users. Efficiency ensures that a trader paying commission should consider the present prices to be the only relevant information in the history of prices.

Hence, corresponding to these two different assumptions, there are controversial results discussed in the literature in terms of the role of the futures markets. Of course, there is little dispute about the role of the futures markets in providing a mechanism for risk sharing. However, many conflicting views remain about their role as a mechanism for predicting spot prices, or price discovery, or, in other words, the efficiency of futures markets. Helmuth (1981) studied the performance of the live cattle futures contracts and drew some rather strong conclusions: "Based on the theory of efficient markets, the existence of the phenomenon described in this report provides strong evidence that...the futures market is operating with a consistent, systematic,

predictable downward bias. Such a conclusion means that...the futures market is not fulfilling its economic purpose of providing a hedging vehicle to all producers." (page 356) Helmuth's conclusion and the methodology used in his study have been criticized later by many researchers. In their studies, Kolb and Gay (1983) wrote: "the conclusion supported by this new methodology strongly opposes Helmuth's conclusion. In fact, it appears that ... futures contracts have exhibited exemplary price work behavior over the period examined." (page 55)

Since the issues of market efficiency, hedging effectiveness, and price discovery are all interrelated, in the sense that they are tested by similar or identical statistical techniques, this study is not designed to distinguish one from the other. Rather, it puts the emphasis on the adequacy of the futures prices in the role of price discovery. Price discovery is the process by which new information affecting asset values becomes reflected in market prices. It refers to the use of futures prices for pricing cash market transaction. There are three points associated with the term "price discovery." First, in order to be an "efficient" price predicting mechanism, futures markets do not have to be always right; it is enough that they are just right on average. That is, one of the definitions of efficiency is that knowledge of futures prices cannot be used along with knowledge of present and past cash prices by speculators to

earn any more than a fair competitive premium. Spectacular short-term losses and gains, while surely allowed, would tend to cancel each other out over the long run. Second, other predictors could also be right on average, which brings up an interesting point. If two predictors are both unbiased, then the usual way to decide which one is more "efficient" is to choose the one with the smaller variance. However, in choosing between price forecasts, a better rule might be to choose the one whose variance is closer to that of the price being predicted. If one of the predictors is the futures market (whose efficiency is generally not questioned) and the other is an econometric model with a similar variance to the spot price series, then the question arises as to whether the forecast from one method, say, using the futures price, could significantly improve the performance of the other predictor. Third, hedgers (or speculators) are entering a futures market based not only on what they think will happen, but also based on what they fear will happen. A hedger may not think that prices will fall, but will fear such an event to the point of buying "insurance", i.e., hedging in futures contracts. If they always did this, then enough speculator activity would push the price to its "efficiently forecasted" level. But in the interim a short-term bias reflecting this insurance premium would exist.

Little work has been done to examine the price discovery role of crude oil futures, and to establish the existence of

a stable long-run relationship between crude oil spot and futures prices and the direction of causality (lead-lag). DOE/EIA (1986) issued a report about using Petroleum futures prices as the predictors of cash prices. The product studied in the report is distillate heating oil. Like many other studies on the theory of price discovery of futures prices, it employed standard econometric methods. Moreover, it did not use any tests to investigate the long-run relationships between spot prices and futures prices. However, the relationship is critical in such studies. Before we get into any practice to test as to whether the futures prices can provide information for forming the spot prices, we should first make sure that a long-run relationship exists between the two price series. If there is no long-run relationship at all between them, that is, the two price series do not follow the same moving pattern over time, there is then no point in talking about how the futures prices can provide information about the formation of spot prices. Ignoring the first step can lead to spurious results. If futures price series and spot price series do not share the same intertemporal characteristics, in other words, they are not integrated of the same order, the procedure that runs the regressions between these two series are incorrect due to the violation of the assumptions underlying the simple regression. Therefore it is argued here that the issues of the price discovery should consist of two parts. The first part tests the existence of a

stable long-run relationship between the spot and futures prices. The second part hinges on the results from the first one. If there is no strong statistical evidence to show the existence of such a relationship, the investigation comes to an end. If the results from the first part ascertain that such a relationship is well established, then the direction of causality (lead-lag) will be tested to examine the discovery role of futures prices. In this dissertation I examine the price discovery role of futures prices of the crude oil futures market.by following these two steps.

For the first part, several different methods, including the conventional methods used in the DOE/EIA report and some new techniques, will be implemented to test whether there exists a stable long-run relationship between crude oil futures prices and the spot price. Provided that the relationship between them is ascertained, then I shall attempt to determine whether the spot price leads futures prices or vice versa. From the results presented, two points will become clear. First, there exists a stable long-run relationship between one-month-ahead crude oil futures price and the spot price. However, no stable long-run relationships can be found between the spot price and the futures prices for more than one month ahead. Second, though a stable long-run relationship exists between the spot price and one-month-ahead futures price, the spot market dominates the futures market, which means that the spot price leads the futures price.

The remainder of this chapter is organized as follows. We first provide a brief overview of the data used in this study, indicating a relationship between the futures and cash markets on a "raw data" basis. Second we present the conventional methods used in the DOE/EIA report (1986), namely, simple regression and combined regression or simulation. Even though the results obtained from them are only suggestive we can still get some intuitive perspective of the movement of the price series. Third, the methods used to test the relationship between the two prices are described. Among them are the integration test and the cointegration test. In order to test the direction of causality, the Garbade and Silber approach and the Granger causality test are implemented in the next two sections. Following this, we apply an error correction model to investigate the dynamics of the long run relationship between the spot price and futures price. The chapter concludes with an assessment of the usefulness of futures prices in forecasting the spot price.

Data Analysis

Futures trading has exploded since 1970. Both the number of futures markets and the participation has increased rapidly since then. In the energy futures market, contracts for petroleum products for delivery 1 to 12 months in the future are available for distillate, motor gasoline, propane, and crude oil. The crude oil futures market has been in operation

since March 1983. In less than ten years, this futures market has become the keystone of a new international pricing system that, for the time being at least, has ended the price domination of the Organization of Petroleum Exchange Countries cartel. Due to many uncertain factors, such as the instability of prices due to political influence, natural disasters and accidents, wars, and the intensified competition from other forms of substitutable energy, crude oil futures provide an ideal tool for risk-sharing. Based on this, it is thus reasonable to say that the futures prices can be also serving as good predictors for the spot prices.

The following preliminary figures and tables suggest that there is a close relationship between the spot and futures prices. Figure 2-1 shows the monthly values for the spot prices series since 1984. Two things are apparent from it. First, crude oil prices have been declining since late-1985; Second, this decline has been irregular. The fact that the spot prices followed a negative trend over this period is important because it helps to explain why the futures prices follow a negative trend as well. The longer the length of the futures contracts, the smaller the futures prices were (that is, at time t, the t+1+n-month-ahead futures price is generally less than the t+1-month-ahead price) which indicates that over time the futures market has been more pessimistic about crude oil prices than was actually warranted. It might be expected, however, that, all other factors being equal,

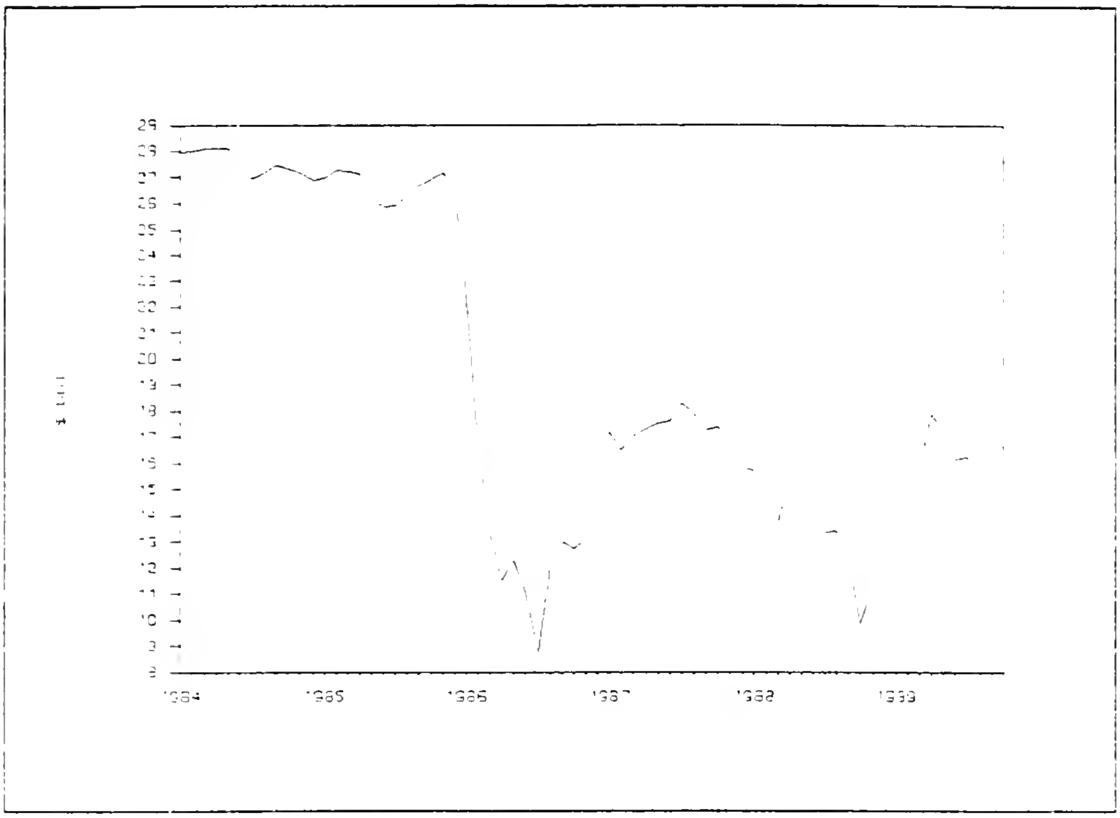

Figure 2.1. Crude Oil Spot Prices

futures prices would exceed spot prices by a small amount. The reason is that, in order for the speculators to participate in the futures market, they will expect to receive a premium for bearing a portion of the market risk due to the fluctuation prices. Also, since these are nominal prices, it would be expected that futures prices should experience some upward pressure because of the inflation rate. However, both of these upward biases can not be overstated because they could be offset by at least two other factors. First, the cost of storage, together with the current spot price, acts as an upper bound on the futures price, since there would be no incentive to buy futures contracts which exceed the sum of the spot price and the storage cost. Second, there may be strong expectations in the marketplace that prices are going to fall. This was the case from 1984 through 1989. The spot prices are plotted against the 1-, 3-, 6-, and 9-month-ahead futures prices in Figure 2-2 through 2-5, respectively.

One problem concerning the futures prices is the choice of the daily futures prices in a month which should be used to represent the future price for that month. If futures markets are efficient, then it should be true that all the contracts prices (1-month-ahead, 2-month-ahead, etc.) on any given day contain all of the information known about the market up to that time. Averaging prices throughout the month is not desirable, because it detracts from the information available from the most recent prices. If an analyst is updating a model

which contains a time series of futures prices as an independent variable, he needs only to choose the most recent price as the current observation. Following this argument, only the futures prices available on one reporting day per month need to be used to represent a monthly value in a time series. For most of this study, the price reported on the 15th day of each month will be used if the 15th day is a trading day. If it is not, then the closest adjacent day from 15th which is a trading day will be used. Picking mid-month values is less prone to bias than first- or end-of-month ones since large institutional investors often use computer trading programs to close out their position at the end of certain months, giving rise to extreme fluctuations in the prices of futures contracts on these days.

Table 2-1 provides the mean, standard deviation, maximum, and minimum for the following prices: spot price and futures prices for 1-, 3-, 6-, and 9-month-ahead contracts. The 2-month-ahead contracted is not used because it is very closely correlated with the 1-month and 3-month-ahead ones. The 4-, 5-, 7-, and 8- month contracts are not examined either because they are found to be closely correlated with 3-, 6-, and 9-month contracts. In this analysis, the actual series used are lagged the number of months in the futures contracts. For instance, the December 1985 1-month futures price is that actually observed in the November 1985 for delivery 1 month later. For purposes of statistical analysis, the 1-month-ahead

contract observed in November is used for predicting (or being correlated with) cash prices one month later. Cross correlations for these series are shown in Table 2-2.

As shown, the mean of crude oil spot price from January 1984 through July 1989 is $19.33 per barrel, while the mean futures prices for 1-, 3-, 6- and 9-month ahead are slightly larger than the mean of spot price, as expected. The table also shows that the correlation between these series falls off from 0.95 for 1-month ahead, progressively declining to 0.62 for 9-month ahead. Figures 2.2 through 2.5 also demonstrate clearly that the 1-month-ahead futures price closely mimics the actual spot price, while the correlation diminishes gradually in the 3-, 6- and 9-month graphs. But the graphs also show more. First, in late-1985, all the futures prices falsely signaled a large drop in the spot price, and the more months ahead the futures prices are, the larger the gap between the futures and spot prices. Second, the futures prices repeated this false signal in late 1988, though to a smaller degree. Third, the futures prices did correct such wrong signals after a certain period of time, although the more months ahead futures prices took longer time to adjust.

Another preliminary way to view the futures markets is to calculate the ratio of futures prices divided by spot prices for the same month. Under the ideal conditions, the statistics would have a mean of 1 and a standard deviation approaching zero. Table 2-3 presents the mean ratios and

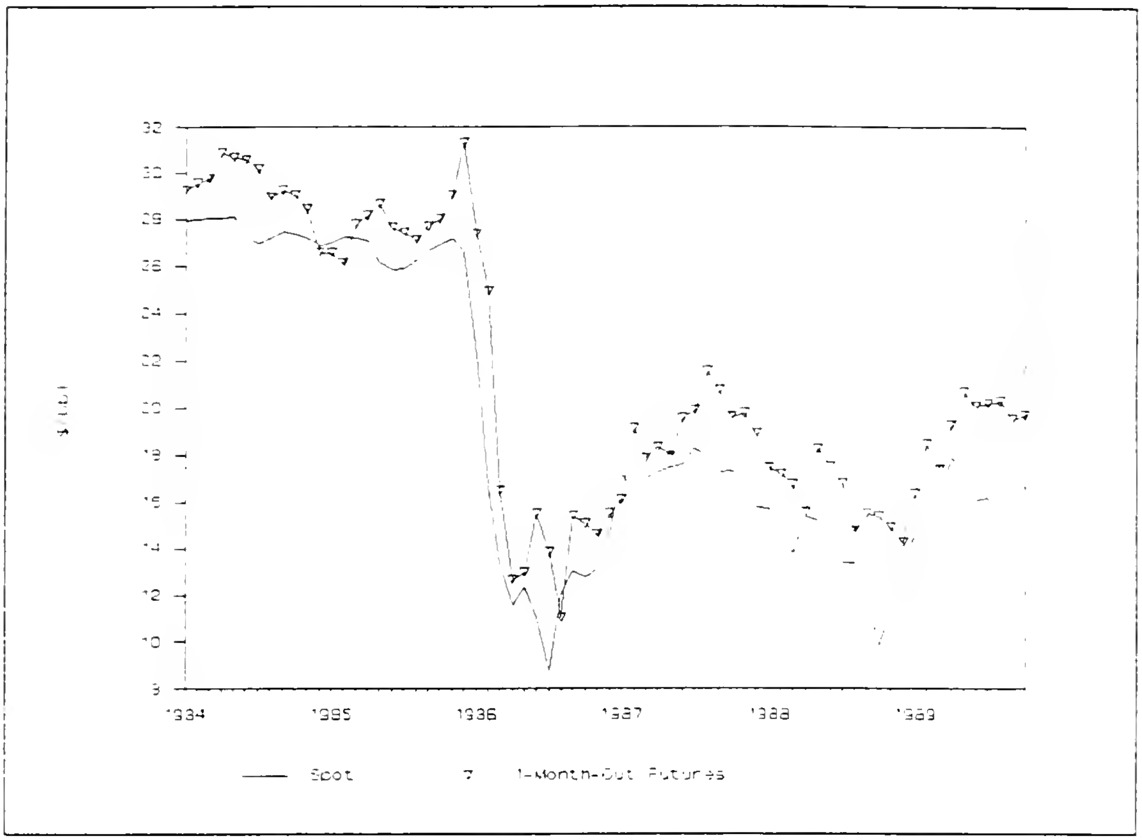

Figure 2.2 Oil Spot & Futures Prices

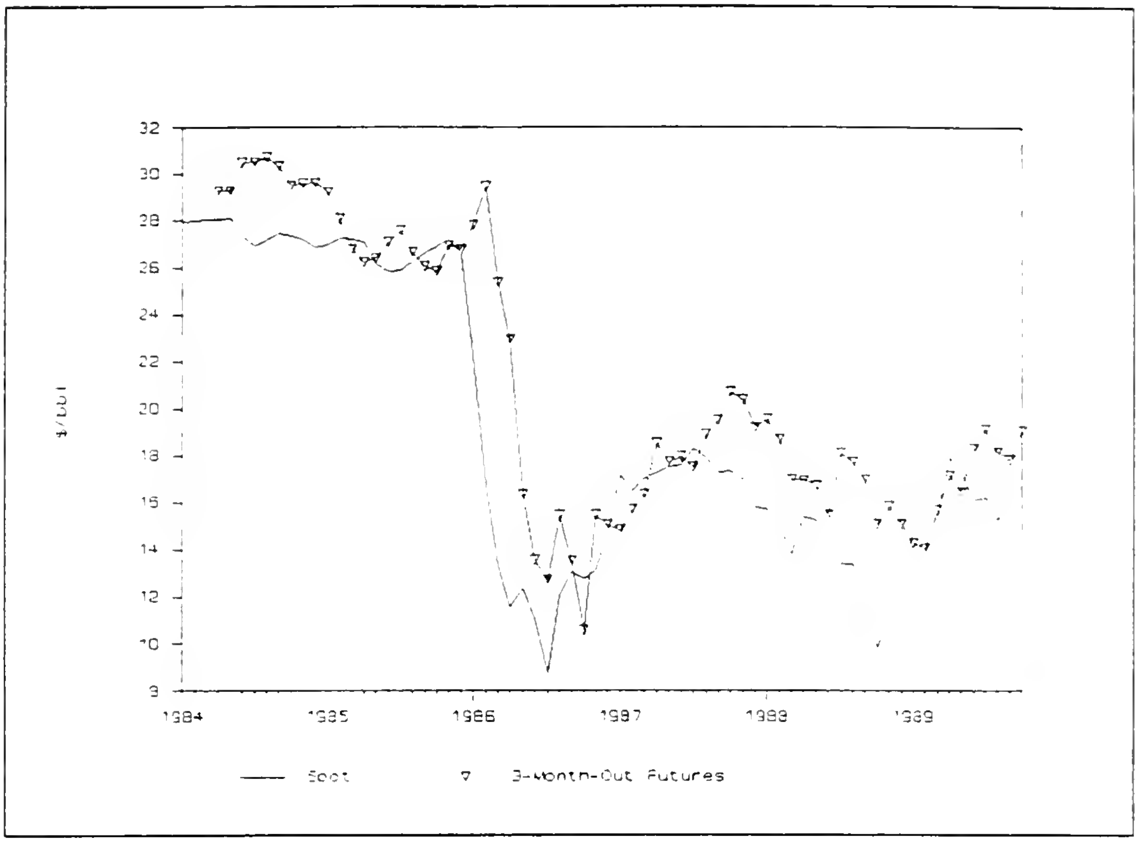

Figure 2.3 Oil Spot & Futures Prices

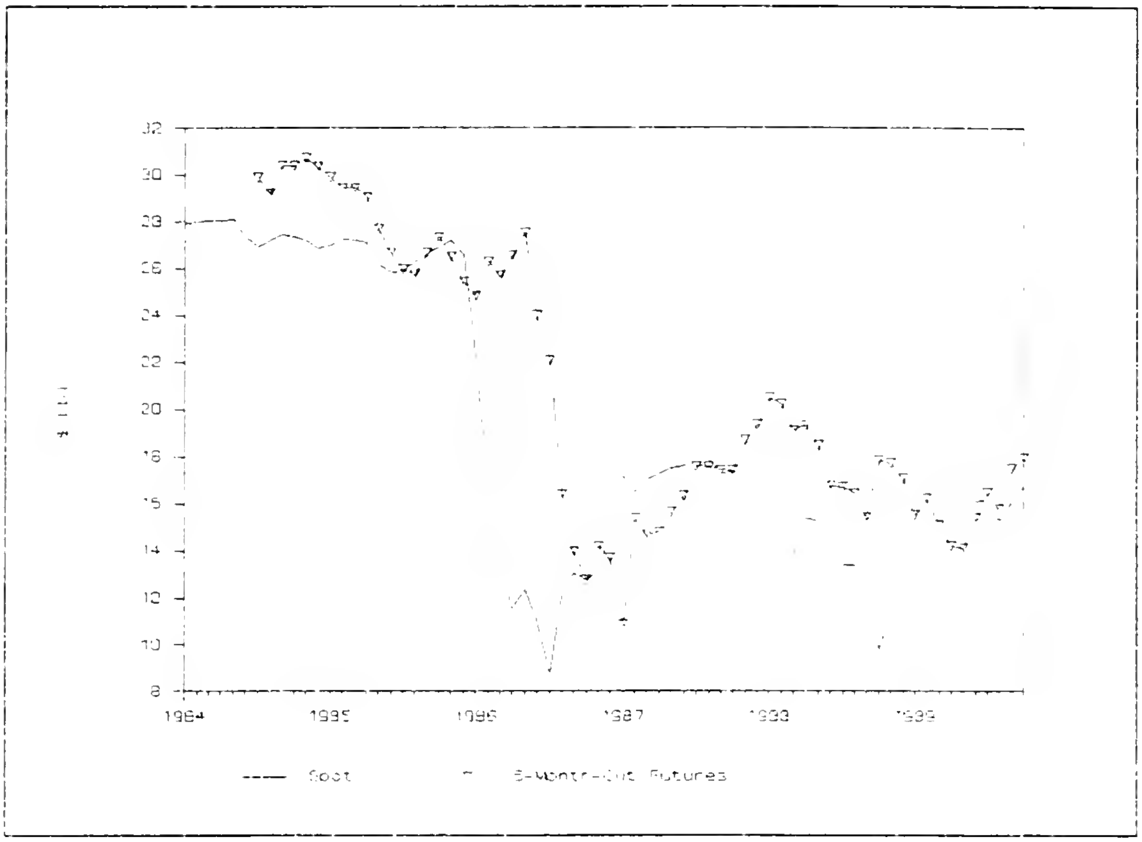

Figure 2.4 Oil Spot & Futures Prices

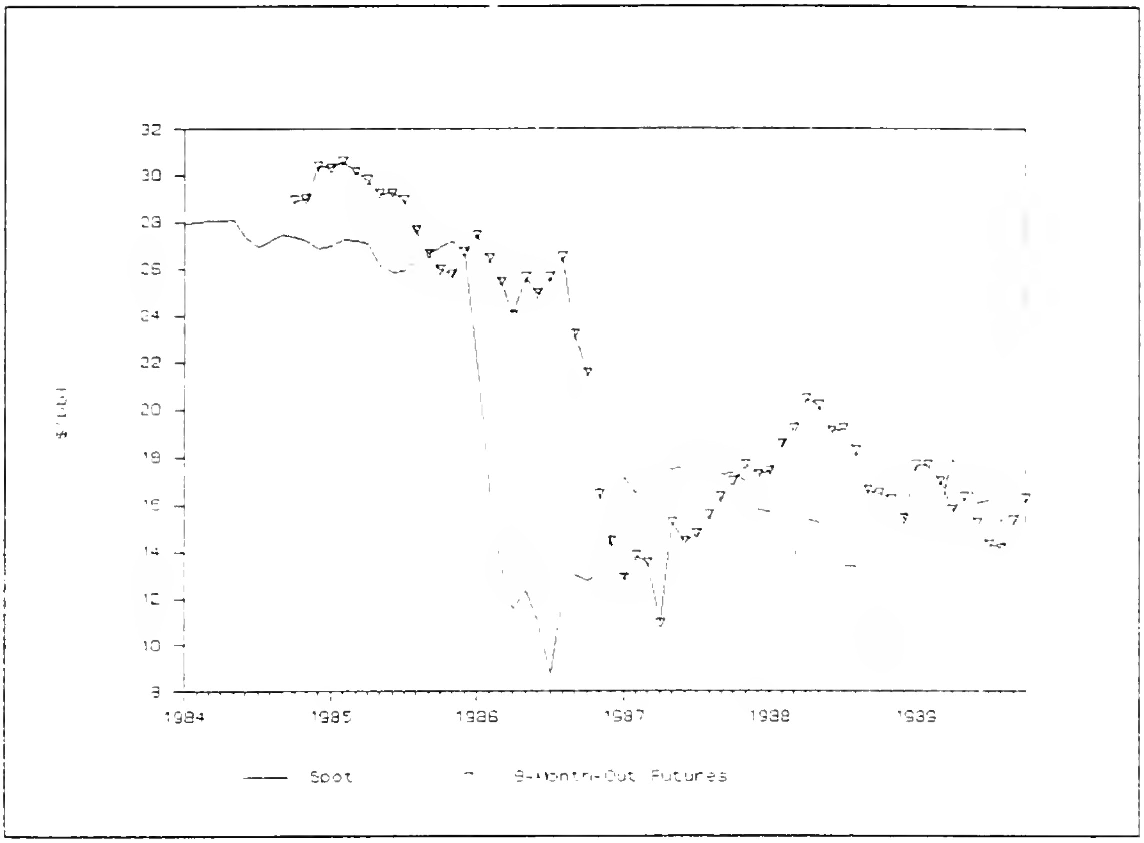

Figure 2.5 Oil Spot & Futures Prices

standard deviations for these calculations. Not surprisingly, the ratios of 1-month-ahead and 3-month-ahead are closest to 1.0, and as expected, the ratio of 1-month-ahead futures has the smallest standard deviation.

Figures 2-6 through 2-9 show the ratios of futures prices to spot prices for the corresponding time periods. It is obvious that the more months ahead the futures prices are, the larger the fluctuation is. There is a slightly downward shift in the graphs indicating that over time the futures market has been pessimistic about crude oil prices than actually warranted. Spot prices were falling, but the futures prices expected them to fall even more during this period.

Using Crude Oil Futures Prices as Predictors of The Spot Price

In this section, the results of a number of alternative methods to test the relationship between crude oil futures prices and the spot price are presented and analyzed. The specifications include simple regression to update current data series, and a simulation which uses formulas to "combine" regression results and known futures prices. These two methods are used in EIA/DOE report (1986). The advantage of these methods is simplicity, even though the usefulness of the results is limited. Despite their shortcomings, these intuitive methods help to reveal the potential prospective relationships which exist between the two price series. It is a good place to start. If the results obtained from them are

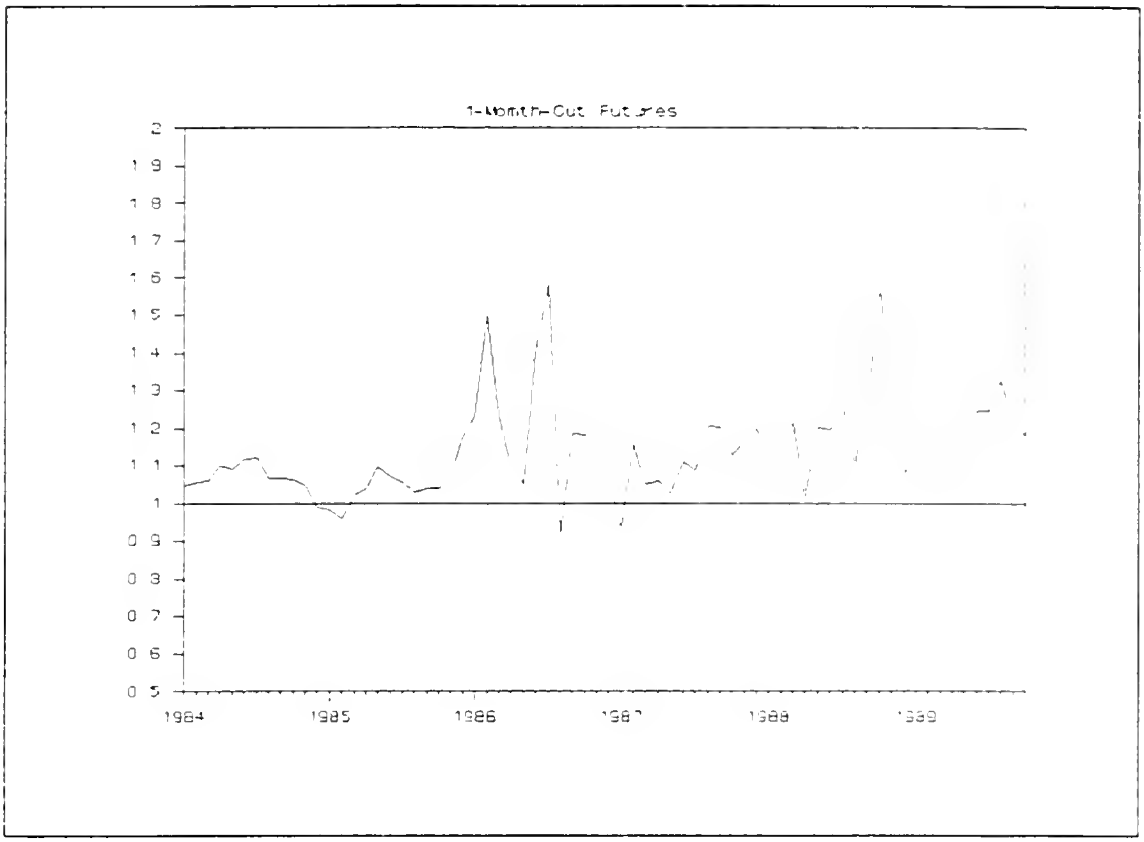

Figure 2.6 Price Ratio: Futures/Spot

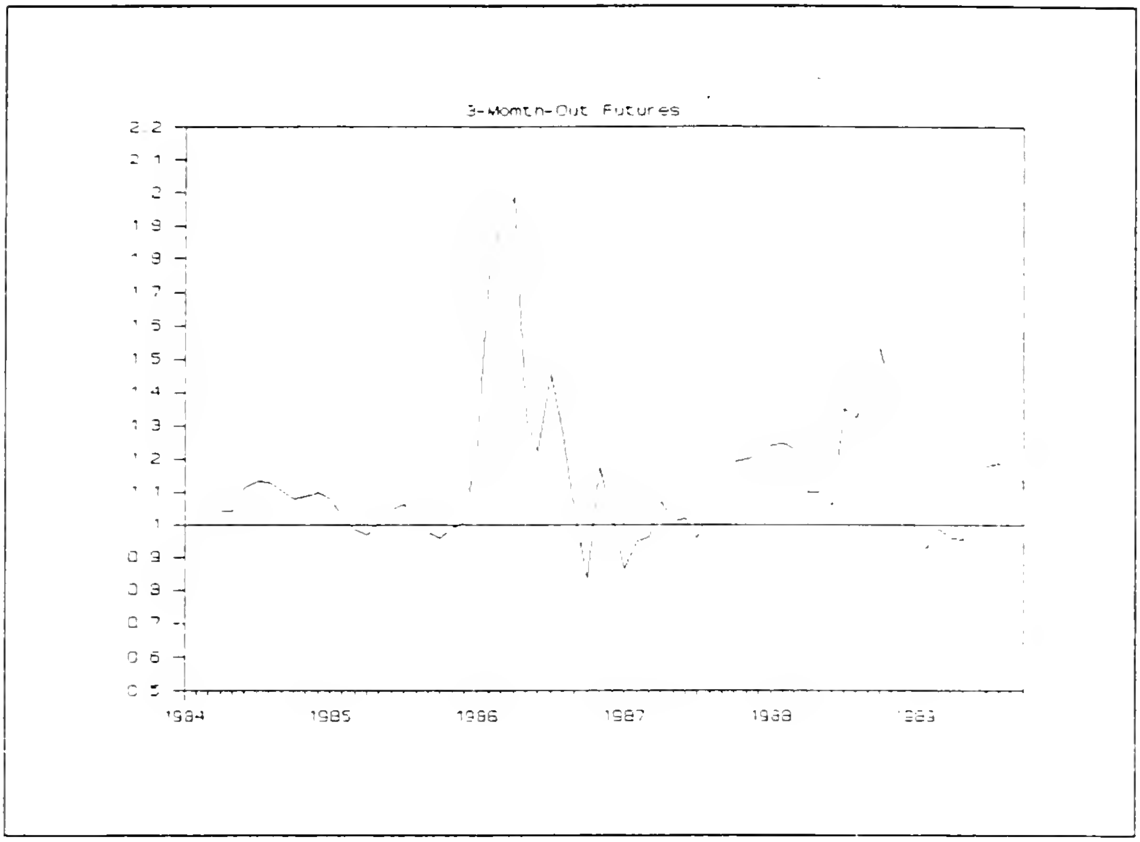

Figure 2.7 Price Ratio: Futures/Spot

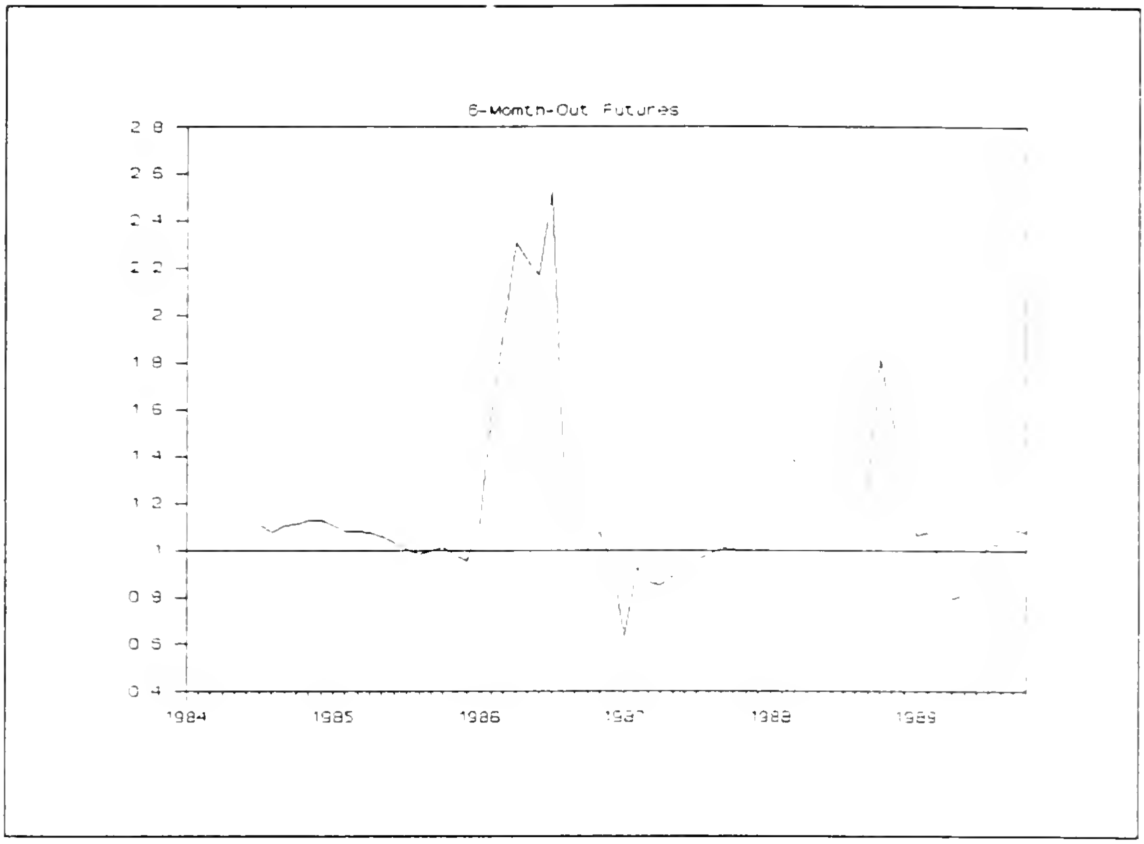

Figure 2.8 Price Ratio: Futures/Spot

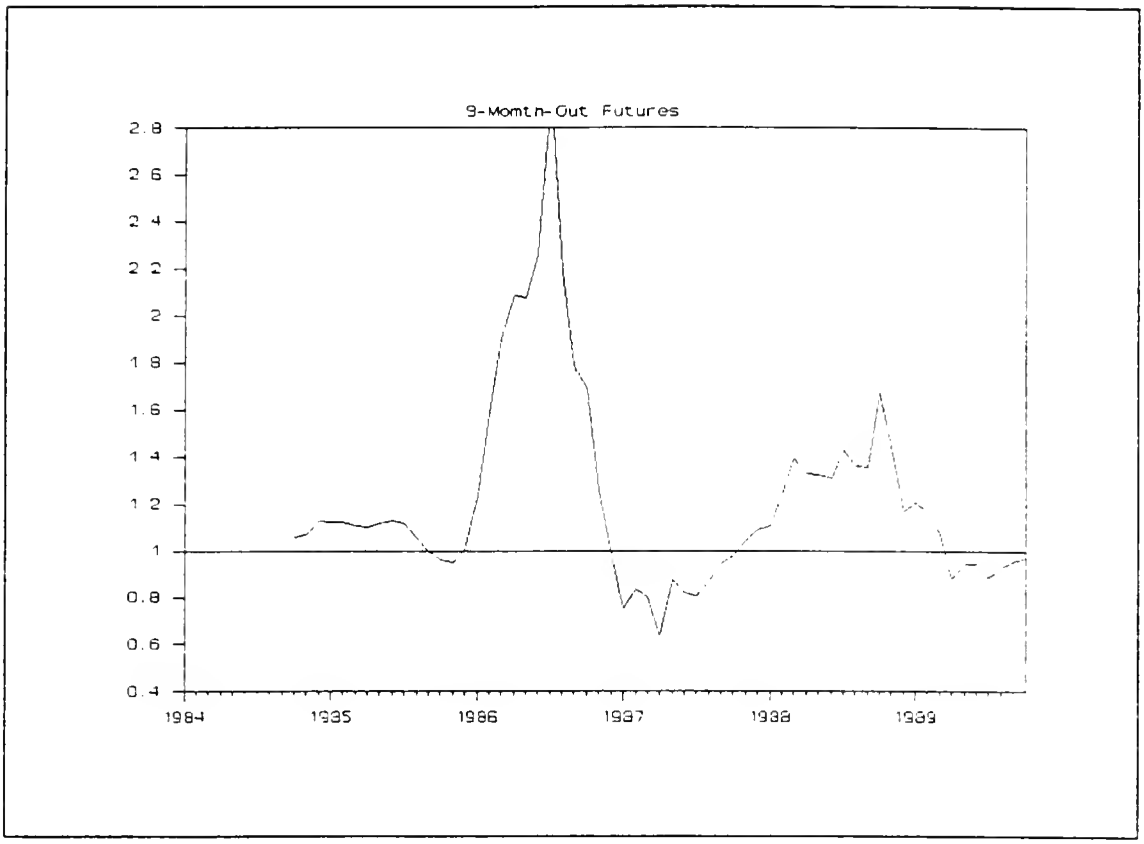

Figure 2.9 Price Ratio: Futures/Spot

negative, suggesting intuitively that these two variables are not related at all, then there is no need to go any further.

Using Futures Prices to Update Current Data

The first method that the futures data could be used is to update data series in those cases when official data lag the current calendar month by a few months. To determine if futures prices could be used in this manner four estimations are attempted. The crude oil prices reported by IECCM of the World Bank are regressed on the New York Mercantile Exchange futures prices for crude oil using 1-month, 3-month, 6-month and 9-month ahead contract price. Thus to fill in missing data points the following equations are estimated:

$$P_t = \alpha + \beta \ FP_{t,1} \quad (2\text{-}1)$$

$$P_t = \alpha + \beta \ FP_{t,3} \quad (2\text{-}2)$$

$$P_t = \alpha + \beta \ FP_{t,6} \quad (2\text{-}3)$$

$$P_t = \alpha + \beta \ FP_{t,9} \quad (2\text{-}4)$$

where

P_t = crude oil price at time t;

$FP_{t,j}$ = j-month-ahead futures prices for delivery at time t, for j = 1, 3, 6, 9;

α, β = regression coefficients.

The effect of lagging the futures prices by 1-, 3-, 6- and 9-month respectively is to regress the current price on a

futures price for delivery in the current month. Table 2-4 gives the results of the estimation. When equations (2-1) and (2-3) are estimated and corrected for the expected autocorrelation, the 1- and 6- month ahead futures crude oil prices are seen to be significant predictors of the spot price. Thus it appears that the 1- and 6- month ahead contract prices can be used to fill in the missing data values; When the 3- and 9- step ahead prices are used, the estimates are not statistically significant. Two interesting points here are worth mentioning. First, while the 3-month-ahead futures price has no significant effect on the spot price, the 6-month ahead futures price does. One possible explanation is that there are coincidentally two competing forces at work over this time period. Inflationary expectations and the risk premium would both tend to increase distant futures prices, while the long-run negative trend in spot prices would work to depress futures prices. If there had been a strong upward trend, then the 3-month-ahead futures price might have had a significant role. Second, while both 1- and 6-month ahead futures prices are significant, the coefficients have opposite signs however. This may be due to the timing of people's expectation formation. It is obvious that it takes a while before people absorb new information. When crude oil price rises unexpectedly this month, people may expect it to drop late. This will cause the longer-term futures prices to move in the opposite direction of the current spot price.

Combining Model Results and Futures Prices

In the above discussion futures prices were viewed as potential inputs to energy models. Along with other energy related data, decision makers would also have knowledge about futures prices when they make price forecast. Now, however, futures markets will be viewed as a competing forecasting mechanism. The question we are asking is whether the futures prices obtained from the regression model add anything to the prices? We attempt to answer the question by studying the combined forecast based on estimated results and futures prices.

Two estimated crude oil prices are used here: those from (2-1) and (2-3). In both cases reported below, 1-month-ahead futures prices make a significant contribution to the combined forecast, but the results with more-than-1-month ahead futures prices are ambiguous.

Simulations from (2-1) and (2-3) are used to generate the estimation results. First, two equations are estimated, each is in the form:

$$P_t = \alpha + \beta_1 \ MP_t + \beta_2 \ FP_{t,j} \qquad (2\text{-}5)$$

where $MP_{t,j}$ is the price estimated from one of the two models (2-1) and (2-3).

The coefficients β_1 and β_2 become the combining weights and tests for their significance indicate whether the

associated forecast adds anything to the combined forecast in a statistically significant manner. The test of significance for the coefficient α is also a test of the unbiasedness of the combined forecasts. If the estimate of α is not statistically different from zero, then no bias is indicated. In contrast, if it is statistically different from zero, then either an upward or a downward bias is present. The results are given in Table 2-5.

From the tables, we can see that 1-month-ahead futures prices consistently make statistically significant contributions to the combined process (Case 1 and Case 5). However, the 1-month-ahead futures prices generate a bias when they are combined with (2-3) (Case 5). The bias of the combinations would not have been a serious problem if there had not been a consistent trend, since futures prices should be slightly higher than spot prices due to the presence of a "risk premium". Interestingly, the 3-month-ahead futures prices turn out to be significant in Case 2 which combines (2-1). Strangely enough, the 9-month-ahead futures prices are also significant in the model which combines with (2-3) (Case 8). However, since the sign of the bias is not consistent across the two models when more distant futures prices were used. Therefore, again that the general weakness of the predictive ability of futures prices more than 1 month out is confirmed.

Relationship Tests

The results in the previous section assume stationarity of the spot and futures prices. Even though we may get some intuitive idea of the price performance, the basic assumptions underlying the simple regression are no longer valid, when the prices are nonstationary. The results obtained in the sections above are useful only if both spot prices and futures prices are stationary in levels. However, if this is not the case, the results of the of the simple regression would be spurious and misleading. Therefore, it is necessary to test the stationarity and the nature of the stochastic movement of the prices. Hence, we will employ the integration and cointegration tests below to take these aspects into account.

Integration Test

Many macroeconomic variables are often found to be nonstationary in levels. It is an empirical fact that these variables appear to be integrated of order 1 (stationary in the first differences), or to possess unit roots. Integration tests are designed to help to evaluate the nature of the nonstationarity of economic variables. In other words, whether they are stationary in levels or in differences of some order.

Suppose there are two economic variables which are nonstationary. The question to ask is whether they move together over time. The cointegration test aims at detecting whether there exists a stable relationship between the levels

of two economic variables. In the example here, we try to link the crude oil spot price P_t and the futures price and test the relationship between them. If a stable relationship exists, then it may be possible to make quantitative inferences about the crude oil price from the observations of the futures prices.

We will implement the integration test to examine the stationarity of the crude oil spot price and futures price. To form a long-run equilibrium relationship, the two variables must share the same intertemporal characteristics. That is, they must be integrated of the same order. The dynamic property of a single series can be described by how often it needs to be differencd to achieve time-invariant linear properties and provide a stationary process. A series that has at least invariant mean and variance and whose autocorrelation has "short memory" is called I(0), or "integrated of order zero". If, on the other hand, a series needs to be differenced Δ times to become I(0), it is said to be integrated of order Δ, denoted as I(Δ).

The order of integration is inferred by testing for unit roots. The most widely applied unit root tests are:

CRDW: Durbin-Watson Test of Sargan and Bhagrava (1983);

DF: the Dickey-Fuller test;

ADF: the augmented Dicky-Fuller test (1979), (1981);

In all of these tests the null hypothesis is that the series are I(1), that is, H_0: $X_t \sim I(1)$. The three statistics used in this analysis are as follows:

CRDW: $X_t = \alpha + e_t$

H_0: $X_t \sim I(1)$, if CRDW >= .532 at 99% level;

DF: $\Delta e_t = \alpha + \beta e_{t-1} + v_t$

H_0: $X_t \sim I(1)$, if β is negative and has a t-statistic lower than -3.37 (95%) or -4.07 (99%);

ADF: $\Delta e_t = \alpha + \beta e_t + \Sigma_{i=1}^{n} \gamma_i \Delta e_{t-i} + v_t$

H_0: $X_t \sim I(1)$, if β is negative and has a t-statistic lower than -3.17 (95%) or -3.37 (99%);

where e_t are the residuals from X_t regression (CRDW) and n is selected to be large enough to ensure that the residuals v_t are white noise. A statistically significant and negative sign of the coefficients β signifies that changes can be reversed over time, and the level is stable.

The Sargan-Bhagrava (CRDW), Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) test statistics are reported in Table 2-6 and 2-7. The results in table 2-6 show that all the series are nonstationary at 99% level of significance. Therefore, the rates of change of all the variables are tested to see whether they are stationary. From Table 2-7, it is apparent that all of the rates of change are stable at the

same level of significance. Thus, all the prices are integrated of the first order, that is, I(1). This implies that the levels of crude oil spot price and each of the four futures prices show similar temporal properties. Therefore, the level of the spot price and futures prices are expected to be statistically linked over the long-run, and that the ratios of spot price and futures prices are expected to be constant over time in the long-term.

Cointegration Test

After establishing that crude oil spot price and futures prices are integrated, both of the first order, the next step is to examine whether they are also co-integrated. The idea of this test is that individual economic time series can be integrated of order one, I(1), but certain linear combinations of the series may be stationary, i.e., I(0). That implies that a linear combination of a set of individually nonstationary economic variables may be stationary. Formally, two variables P_t and Q_t are said to be co-integrated if there exists a constant C such that $Z_t = P_t - C\, Q_t$, is integrated of order zero I(0). Z_t is then stationary with a positive, finite spectrum at zero frequency. This is a rather special condition, because it implies that both series individually have extremely important long-run components. However, in forming Z_t these long-run components cancel out and disappear. To test whether the series are cointegrated, a two-stage test

similar to the one applied to test for integration is followed. In the first stage, the coefficient C is estimated by OLS; in the second stage, the resulting series $Z_t = P - \hat{C}\, FP_{t,j}$ is tested as I(0) rather than I(1). The same procedure employed in the section above, is used here to test Z_t. Table 2-8 gives results of the test.

It is clear, from the table below, that the only futures price variable with all the statistics CRDW, DF, ADF being significant at 95 percent confidence level is the 1-month-ahead futures prices. None of the other futures price variables have significant ADF values. Therefore, it can be concluded that only 1-month-ahead futures price is cointegrated with the spot price; the hypotheses about other futures prices, however, cannot be accepted at the 95 percent significance level.

The findings that the spot price and the 1-month-ahead futures price of crude oil are I(1) and a certain liner combination of them is I(0) have clearly demonstrated a long-run relationship between the spot and futures prices. The remaining question now is what direction of "causation" this relationship follows, that is, which price leads, and which price follows. I attempt to answer this question in the next section.

Causality Tests

It has been ascertained above that a stable long-run relationship exists between the spot price and 1 month ahead futures prices. The next problem is to determine the direction of causation between the spot price and the futures price. In this section the Garbade and Silber approach and the Granger causality test procedure will be employed to investigate the direction of causality. Since a long-run relationship is only found between the spot price and 1-month-ahead futures price, we let F_t denote the 1-month-ahead futures price later on in this chapter, unless otherwise indicated.

The Garbade and Silber Approach

The essence of the price discovery function of futures markets hinges on whether new information is reflected first in changed futures prices or in changed cash prices. The Garbade and Silber approach provides a framework for analyzing whether one market is dominant in terms of information flows and price discovery. The model can be applied to the crude oil markets, with one minor modification. The prices, both spot and futures, are often reported on a monthly basis while this only lengthens the transaction period, and the fundamental characters of the monthly data are identical to those of daily reported price.

Garbade and Silber propose the following model of price behavior:

$$\begin{bmatrix} S_t \\ F_t \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} 1-\beta_s & \beta_s \\ \beta_f & 1-\beta_f \end{bmatrix} \begin{bmatrix} S_{t-1} \\ F_{t-1} \end{bmatrix} + \begin{bmatrix} u_t \\ v_t \end{bmatrix} \qquad (2\text{-}6)$$

where S_t is the logarithm of the spot price for month t and F_t is the logarithm of the 1-month-ahead futures price for the same month. The constant terms, α_s and α_f, have been added to equation (2-6) to capture any secular price trends in the data and any persistent differences between spot price and futures price attributable to different quotation conventions. The coefficient β_s and β_f reflect the influence of the lagged price from one market on the current price in the other market. Since the spot and futures market prices are for the same commodity, one would anticipate that both β_s and β_f are non-negative. The ratio $\beta_s/(\beta_s + \beta_f)$ can be used to examine the price discovery relationship between the two markets. If the ratio equals unity (so that $\beta_f = 0$), convergence of spot and futures prices occurs because the spot price always moves towards the futures prices. This is an extreme case where the spot market is a "pure satellite" of the futures market. If the ratio $\beta_s/(\beta_s + \beta_f)$ equals zero (so that $\beta_s = 0$), then the futures prices always adjust towards the spot prices and the futures market is a pure satellite. Intermediate values between zero and one imply mutual adjustments and feedback effects between the markets.

Equation (2-6) can be solved for $F_t - S_t$ as a function of $F_{t-1} - S_{t-1}$ to yield:

$$F_t - S_t = \alpha + \delta(F_{t-1} - S_{t-1}) + e_t \qquad (2-7)$$

where $\alpha = \alpha_f - \alpha_s$, $\delta = 1 - \beta_f - \beta_s$, and $e_t = u_t - v_t$. As can be observed in equation (2-7), δ reflects the speed of convergence between spot and futures prices. If δ is small, relatively little difference between futures and spot prices in month t-1 persists to month t. Prices will therefore converge quickly.

We rearrange equations (2-6) algebraically as follows, so that they can be estimated via ordinary least squares:

$$\begin{bmatrix} S_t - S_{t-1} \\ F_t - F_{t-1} \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} \beta_s \\ -\beta_f \end{bmatrix} [F_{t-1} - S_{t-1}] + \begin{bmatrix} u_t \\ v_t \end{bmatrix} \qquad (2-8)$$

The estimates β obtained with ordinary least squares are summarized in Table (2-9). $\beta_s/(\beta_s + \beta_f)$ represents the relative contribution of the futures market to the price discovery process, and δ measures the rate of the convergence of futures and spot prices. Two results have emerged. First, the estimate of β_f is significantly positive. This finding shows that the crude oil spot price leads the futures price in incorporating new pricing information. Second, the estimate of β_c is neither

positive nor significant, suggesting that little feedback of pricing information occurs from the futures market to the spot market. The derived estimate of the parameter δ indicates that less than half of the differential between futures and spot prices in month t-1 persists to month t. This implies that arbitrage is undertaken rather quickly to bring about price convergence between the two markets.

Granger Causality Test

The lead-lag relationship can also be examined through Granger's causality test, which states that the stationary linear combination of levels must Granger-cause the change in at least one of the cointegrated variables. It is well known that causality in the sense of Granger from a variable z_1 to variable z_2 can arise for two reasons. The variable z_1 may cause z_2 in the common-language sense, or instead the variable z_1 may anticipate or forecast z_2. In the former case an intervention which changes the stochastic process for z_1 will change z_2, while in the latter case an intervention which changes the stochastic process for z_2 will change the behavior z_1. The Granger's test is designed to examine whether two time series are generated separately from each other. When they are generated separately, one time series provides no information for characterizing the other.

Following Granger (1969), the simple causal model is

$$P_t = \Sigma_{i=1}^{m} \alpha_{1i} P_{t-i} + \Sigma_{j=1}^{m} \beta_{1j} F_{t-j} + \epsilon_{1t}, \qquad (2\text{-}9)$$

$$F_t = \Sigma_{i=1}^{m} \alpha_{2i} P_{t-i} + \Sigma_{j=1}^{m} \beta_{2j} F_{t-j} + \epsilon_{2t}, \qquad (2\text{-}10)$$

where P_t denotes the crude oil spot price and F_t the 1-month-ahead futures price, and ϵ_{1t} and ϵ_{2t} are taken to be uncorrelated white-noise series.

If some of β_{1j}'s are not zero, then P_t is said to cause F_t. Similarly if some β_{2j}'s are not zero, then F_t is said to cause P_t . If the events both occur, then it is said that there is a feedback relationship between P_t and F_t. The usual F-test can be applied to test the null hypothesis that P_t does not cause F_t, i.e., $\beta_{1j} = 0$ for all j, or F_t does not cause P_t, i.e., $\beta_{2j} = 0$ for j.

Equation (2-9) and (2-10) are estimated by the least squares method under the restrictions $\beta_{1j} = 0$ and $\beta_{2j} = 0$ respectively. Table (2-10) summarizes the results. From the table, it is clear that the restrictions imposed on the equation (2-9) are statistically significant at 81% confidence level. In contrast, those on the equation (2-10) are not statistically significant. According to the definition of Granger causality, this suggests that the spot price is causing the future price, but the futures price is not causing the spot price, This conclusion corroborates that obtained in the last section. Hence, it is safe to conclude that the crude

oil futures prices do not play an important role in price discovery and the spot market always leads the futures market.

The Error Correction Model

Now that a long run relationship between the crude oil spot price and the 1-month-ahead futures price and the direction of the causality have been established, we are in a position to study the dynamics of the stochastic movement of the prices. Since the crude oil spot price and 1-month-ahead futures price are cointegrated. An error correction model can be used to examine more closely the relationship between these two variables.

The error correction model (ECM) for cointegrated variables is commonly interpreted as reflecting partial adjustment of one variable to another. Campbell and Shiller (1988) show the error correction models may also arise when one variable forecasts another. The concepts of cointegration and error correction are closely related. Indeed, It has been proven that two variables which are cointegrated have an error correction model representation. An error correction model for two variables relates the changes in the variables to lagged changes and a lagged linear combination of levels. The linear combination of levels which enters the error correction model is just that combination which is stationary in levels. In other words, when two variables are cointegrated, there always exists a valid error correction model for the data. An error

correction model can be thought of as a description of the stochastic process by which the variables eliminate or correct the equilibrium error.

Let us consider the crude oil spot price P_t and 1-month-ahead futures price FP_t. We know that both of them are integrated of order one and therefore they are cointegrated, i.e., their linear combination is integrated of order zero. Therefore they are said to be cointegrated. Define the residuals from the cointegrated regression $Z_t = P - \hat{C}\ FP_t$ as the equilibrium error, which enters the error correction model below:

$$\Delta P_t = -\gamma_1 Z_{t-1} + \Sigma_{i=1}^{m} \delta_{1i} \Delta P_{t-i} + \Sigma_{j=1}^{n} \theta_{1j} \Delta FP_{t-j} + \epsilon_{1t} \qquad (2\text{-}11)$$

$$\Delta FP_t = -\gamma_2 Z_{t-1} + \Sigma_{i=1}^{r} \delta_{2i} \Delta P_{t-i} + \Sigma_{j=1}^{s} \theta_{2j} \Delta FP_{t-j} + \epsilon_{2t} \qquad (2\text{-}12)$$

where γ_1, γ_2, δ_i and θ_j are coefficients, ϵ_{1t} and ϵ_{2t} are assumed to be white noises.

A set of equations have been estimated in a descending order of generality. The results are given in the Table 2-11 below. Two main conclusions follow from the error correction model. First, the error correction term Z_t is statistically very significant in equation (2-11), but neither the value of its coefficient nor the t-statistics of the equation (2-12) is significant. Since the value of Z_t measures the deviation from the equilibrium. It suggests that disequilibrium distance plays an important role in the crude oil spot market, implying that the market is often unstable. This is consistent with the

fluctuation of the crude oil spot price in the real world. In contrast, the futures market deviates less away from the equilibrium or and is thus more stable. This justifies the "risk sharing" role of futures markets. Second, overall, equation (2-12) is much better than equation (2-11), in terms of the R^2 (unadjusted and adjusted), the standard error, and the statistical significance of the model. This throws light on the lead-lag question. The changes in futures price are well explained by the changes in the lagged spot prices and futures prices. Moreover, while the lagged spot prices play an important role in equations (2-12), the changes in lagged futures prices are not significant in equation (2-11). Therefore as in the previous section, we have found again that the spot market dominates the futures market, but not vice versa.

Having analyzed the dynamics of the price movement, the next question is about the forecast stability. As an illustration, both equation (2-11) and (2-12) are estimated by using the monthly data from 1984 to 1988, excluding the first seven months of 1989. The results, provided in Table (2-13), are identical to those obtained when the whole sample is used. The forecast values of changes in both spot and futures prices are summarized in Table (2-13). The variance of the difference between actual and predicted values from equation (2-12) is 0.315, which is almost half of that (which is 0.624) from equation (2-11). Once again, this result suggests also that

equation (2-12) is doing much better than the other one in terms of prediction. Above all, we conclude that equation (2-12) should be used to capture the dynamic interaction between these two prices.

Summary

This chapter has been divided into two related parts. First, it has investigated whether there exists a stable long-run relationship between crude oil spot price and futures prices. 1-, 3-, 6- and 9-month ahead futures prices have been used to carry out the test. Both conventional and cointegration test methods have been performed. We find that while there exists a stable long run relationship between the spot price and 1-month-ahead futures price, no such relationships exists between the spot price and the other futures prices.

Second, a dynamic regression testing scheme and Granger causality test have been applied to further investigate the price lead-lag relationships between the spot and 1-month-ahead futures price. The results from both tests leads us to conclude that the crude oil spot price generally leads the futures price in incorporating new pricing information, and that the crude oil spot market always dominates the futures markets. These results suggest that the crude oil futures price does not play a very important role in the price discovery process.

Table 2-1

Selected Statistics for Crude Oil
Spot and Futures Price

Price Series	Mean	S.D.	Max.	Min.
Spot	19.33	6.24	28.11	8.72
Futures				
1-Month-ahead	21.39	5.98	31.35	11.04
3-Month-ahead	21.04	5.96	30.73	10.58
6-Month-ahead	20.93	5.95	30.73	10.86
9-Month-ahead	21.05	5.85	30.62	10.92

Table 2-2

Cross-Correlations for Crude Oil
Spot and Futures Price Series

	Spot	1-Month	3-Month	6-Month	9-Month
Spot	1.00	0.95	0.85	0.69	0.62
1-Month-ahead		1.00	0.87	0.70	0.70
3-Month-ahead			1.00	0.85	0.73
6-Month-ahead				1.00	0.89
9-Month-ahead					1.00

Table 2-3

Selected Statistics for Crude Oil Spot and Futures Price Ratios

Ratio to Spot Price of:	Mean	S.D.	Max.	Min.
Futures:				
1-Month-ahead	1.14	0.13	1.58	0.91
3-Month-ahead	1.14	0.22	1.19	0.37
6-Month-ahead	1.18	0.37	2.53	0.63
9-Month-ahead	1.23	0.43	2.94	0.63

Table 2-4

Regression Coefficients for 1-, 3-, 6- and 9-Month Ahead Crude Oil Futures Prices as Predictors of Spot Prices

Variables	Equations			
	(2.1)	(2.2)	(2.3)	(2.4)
Constant	10.16* (3.09)	13.23* (4.07)	18.18* (5.12)	15.06* (4.16)
$FP_{t,1}$	0.31* (3.49)			
$FP_{t,3}$		0.11 (0.98)		
$FP_{t,6}$			-0.29* (-2.32)	
$FP_{t,9}$				-0.02 (-0.17)
1st-Order Autocorrelation	0.94	0.95	0.96	0.94
R^2	0.96	0.95	0.94	0.93
$\bar{R}^2$	0.96	0.95	0.94	0.93
D-W	1.73	1.15	1.03	1.13
Std. Error	1.28	1.40	1.38	1.47
Estimation Technique	Cochrane-Orcutt			

Notes:

1: t-Statistic in parentheses.

2: * denotes that the coefficients are significant at the 95 percent or higher confidence level.

3: The notations are for all the tables in this dissertation, if not otherwise indicated.

Table 2-5

Regression Coefficients for Equations Combining Crude Oil Price with Futures Prices

Case	Regression Coefficients α	β_1	β_2
1	-0.62 (-0.80)	0.55* (4.20)	0.43* (3.08)
2	-0.03 (-0.04)	0.89* (26.10)	0.10* (3.23)
3	0.42 (0.57)	0.94* (30.11)	0.03 (1.30)
4	0.71 (0.90)	0.95* (30.25)	0.01 (0.44)
5	-1.63 (-2.13)	0.49* (4.12)	0.54* (4.54)
6	-0.38 (-0.45)	0.92* (10.35)	0.09 (1.09)
7	-0.09 (-0.11)	1.00* (15.89)	0.01 (0.16)
8	1.19 (1.50)	1.06* (26.44)	-0.11* (-3.64)

Key:
Case 1: (2-1) and 1-month-ahead futures prices
Case 2: (2-1) and 3-month-ahead futures prices
Case 3: (2-1) and 6-month-ahead futures prices
Case 4: (2-1) and 9-month-ahead futures prices
Case 5: (2-3) and 1-month-ahead futures prices
Case 6: (2-3) and 3-month-ahead futures prices
Case 7: (2-3) and 6-month-ahead futures prices
Case 8: (2-3) and 9-month-ahead futures prices

Table 2-6

Results of Integration Tests for
Crude Oil Spot and Futures Prices

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
P	0.050	-1.37	-1.44
FP1	0.094	-1.62	-1.72
FP3	0.077	-1.52	-1.72
FP6	0.060	-1.36	-1.69
FP9	0.564	-1.03	-1.49

Table 2-7

Results of Integration Tests for First Order Differenced Crude Oil Spot and Futures Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
Δ P	1.13	-4.99	-4.64
Δ FP1	1.65	-6.61	-4.90
Δ FP3	1.71	-6.69	-4.80
Δ FP6	1.72	-6.55	-4.24
Δ FP9	1.80	-6.67	-4.03

Table 2-8

Results of Cointegration Tests for Crude Oil Spot and Futures Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 95%: -3.17)
Case 1	1.507	-9.59	-3.45
Case 2	1.173	-5.32	-2.84
Case 3	0.964	-4.47	-2.87
Case 4	0.119	-4.70	-2.80

Key:

Case 1:	Spot Price vs 1-Month-Ahead Futures Price
Case 2:	Spot Price vs 3-Month-Ahead Futures Price
Case 3:	Spot Price vs 6-Month-Ahead Futures Price
Case 4:	Spot Price vs 9-Month-Ahead Futures Price

Table 2-9

Estimated Coefficients for Futures and Spot Prices
Garbade and Silber's Approach

Parameter	Period 1984M1 - 1989M7
β_s	-0.033 (-0.29)
β_f	0.684 (7.92)
$\beta_s/(\beta_s+\beta_f)$	0.00**
δ	0.40

Notes: ** the calculated value is 0.05, but Garbade and Silber's procedure requires both β_s and β_f are positive.

Table 2-10

Causality On Crude Oil and Futures Prices

Independent	Dependent Variable	
	P_t	F_t
Constant	0.41 (0.44)	1.20 (0.82)
P_{t-1}	1.11 (8.80)	
P_{t-2}	-0.15 (-1.13)	
F_{t-1}		1.02 (8.05)
F_{t-2}		-0.10 (-0.72)
h	1.43	1.38
R^2	0.88	0.79
$\bar{R}^2$	0.88	0.78
S.E.	2.44	3.11
log of likelihood	-143.70	-164.49
Significance of restriction	81%	1%

Table 2-11

Error Correction Model

Equation (2.6.1) (Sample 1984M1 - 1989M7)

$$\Delta P_t = -1.243Z_{t-1} + 1.688\Delta P_{t-1} - 0.074\Delta P_{t-2} - 0.300\Delta P_{t-3}$$

(-1.93) (2.71) (-0.31) (1.22)

$$-0.456\Delta FP_{t-1,1} - 0.123\Delta P_{t-2,1} + 0.035\Delta P_{t-3}$$

(-1.73) (-0.69) (0.34)

$R^2 = 0.30$ $R^2 = 0.20$ S.E. = 1.30 D.W. = 1.93

Equation (2.6.2) (Sample 1984M1 - 1989M7)

$$\Delta FP_{t,1} = -0.078Z_{t-1} + 1.198\Delta P_{t-1} + 0.382\Delta P_{t-2} + 0.138\Delta P_{t-3}$$

(-0.15) (2.42) (2.03) (0.70)

$$-0.433\Delta FP_{t-1,1} - 0.129\Delta P_{t-2,1} - 0.153\Delta P_{t-3}$$

(-2.06) (-0.92) (-1.88)

$R^2 = 0.74$ $R^2 = 0.70$ S.E. = 1.03 D.W. = 2.05

Table 2-12

Error Correction Models and Forecasting Stability

Equation (2.6.1) (Sample 1984M1 - 1988M12)

$$\Delta P_t = -0.243Z_{t-1} + 0.729\Delta P_{t-1} - 0.108\Delta P_{t-2} + 0.534\Delta P_{t-3}$$

(-1.29) (3.33) (-0.38) (1.74)

$$-0.160\Delta FP_{t-1,1} - 0.299\Delta P_{t-2,1} - 0.002\Delta P_{t-3}$$

(-0.69) (-1.42) (-0.22)

$R^2 = 0.28$ $R^2 = 0.18$ S.E. = 1.34 D.W. = 1.91

Equation (2.6.2) (Sample 1984M1 - 1988M12)

$$\Delta FP_{t,1} = 0.143Z_{t-1} + 1.012\Delta P_{t-1} + 0.340\Delta P_{t-2} - 0.024\Delta P_{t-3}$$

(1.00) (6.10) (1.57) (-0.102)

$$-0.292\Delta FP_{t-1,1} - 0.030\Delta P_{t-2,1} - 0.143\Delta P_{t-3}$$

(-1.66) (-0.19) (-1.66)

$R^2 = 0.75$ $R^2 = 0.72$ S.E. = 1.03 D.W. = 2.10

Table 2-13

ECM Predicted Values of Changes in Spot And Future Prices

Time	Spot Price			Futures Price		
	Actual	Pred.	diff.	Actual	Pred.	diff.
1989M1	1.40	-0.04	1.45	2.10	2.91	0.82
1989M2	0.54	1.44	0.90	2.11	0.06	2.05
1989M3	0.71	0.64	0.07	-1.06	0.63	1.69
1989M4	2.06	0.50	1.56	1.87	1.20	0.67
1989M5	-0.65	1.50	2.15	1.40	-0.02	1.42
1989M6	-1.15	-0.77	0.38	-0.60	1.18	1.78
1989M7	0.10	0.29	0.19	0.14	-0.61	0.75

CHAPTER III
FUTURES PRICES AND OPEC CRUDE OIL SUPPLY

Introduction

The relationship between futures prices and OPEC crude oil supply is not as clear as the one between futures prices and crude oil spot price. And little research has been done in this field yet. Naturally, different assumptions will lead to different conclusions.

For instance, if the crude oil futures prices follow a random walk, there will be no relationship at all between OPEC supply and futures prices. As a result, nothing can be used to predict the futures prices. On the contrary, if traders are assumed to have rational expectations then there is a definite relationship between the futures prices and OPEC crude oil supply. It can be argued that speculators bid their futures prices based on their expectations of the market in the near future. The crucial factors in the markets like supply and demand undoubtedly play a very important role in the process of trader's expectations.

The purpose of this chapter is to investigate the relationship between OPEC supply and futures prices. It will become clear that even though some relationship between futures prices and OPEC oil supply could be identified with

elementary methods, these variables are not expected to be stationary. This suggests that the results obtained by the elementary methods can be wrong. As in the last Chapter, we shall first try to determine if a stable relationship exists. Unfortunately, most of the researchers on price discovery have ignored this step and went to the test of causality directly. However, if a stable relationship does not exist, then the results obtained by the Garbade and Silber approach and Granger causality test may lead to incorrect conclusions.

The rest of this chapter is organized as follows. First, we study some prior information about data by using some preliminary methods such as statistical analysis, graphic illustrations and simple regressions. Second, the results from the simple regression are presented next. The characteristics of the time series under consideration will be tested in the following section with the integration and cointegration tests. Even though futures prices and OPEC oil supply are not found to be cointegrated, which suggests that there is no long-run stable relationship between them, the Garbade and Silber approach and Granger causality test are used anyway in the next two sections to show one can get misleading results. And finally, the conclusions are presented briefly.

Data Analysis

In this section, we are going to do some preliminary analysis of the time series we are interested in. The methods

of analysis include graphs, basic statistical analysis, and simple regressions. Figure 3-1 shows the monthly values for the OPEC crude oil production series since 1984. Several things are apparent from it. First, the OPEC crude oil production has had an upward trend. This may explain that the crude oil price has been declining from the peak in the so-called "oil crisis" and has recovered to that level. It also helps to explain why, over time, the futures market has been pessimistic about crude oil prices so that the crude oil futures prices follow a negative trend as well. Traders in the market expect that the upward trend in OPEC production will continue. Secondly, this decline has been irregular, there is no recognizable pattern to follow.

Table 3-1 provides the mean, standard deviation, maximum, and minimum for the following variables: OPEC oil production and futures prices for 1, 3, 6, and 9 month-ahead contracts. Again, the futures prices picked are the same as those stated in the last chapter, that is the 2-month-ahead is very closely correlated with the 1-month and 3-month-ahead ones and the 4-, 5-, 7-, and 8-month-ahead contracts are found to be closely correlated with 3-, 6-, and 9-month contracts. Cross correlations for these series are given in Table 3-2.

As shown in the table 3-1, the mean of OPEC crude oil production from January 1984 through July 1989 is 17.83 million barrels per day. There are two interesting points about table 3-2. First, it shows that the correlation

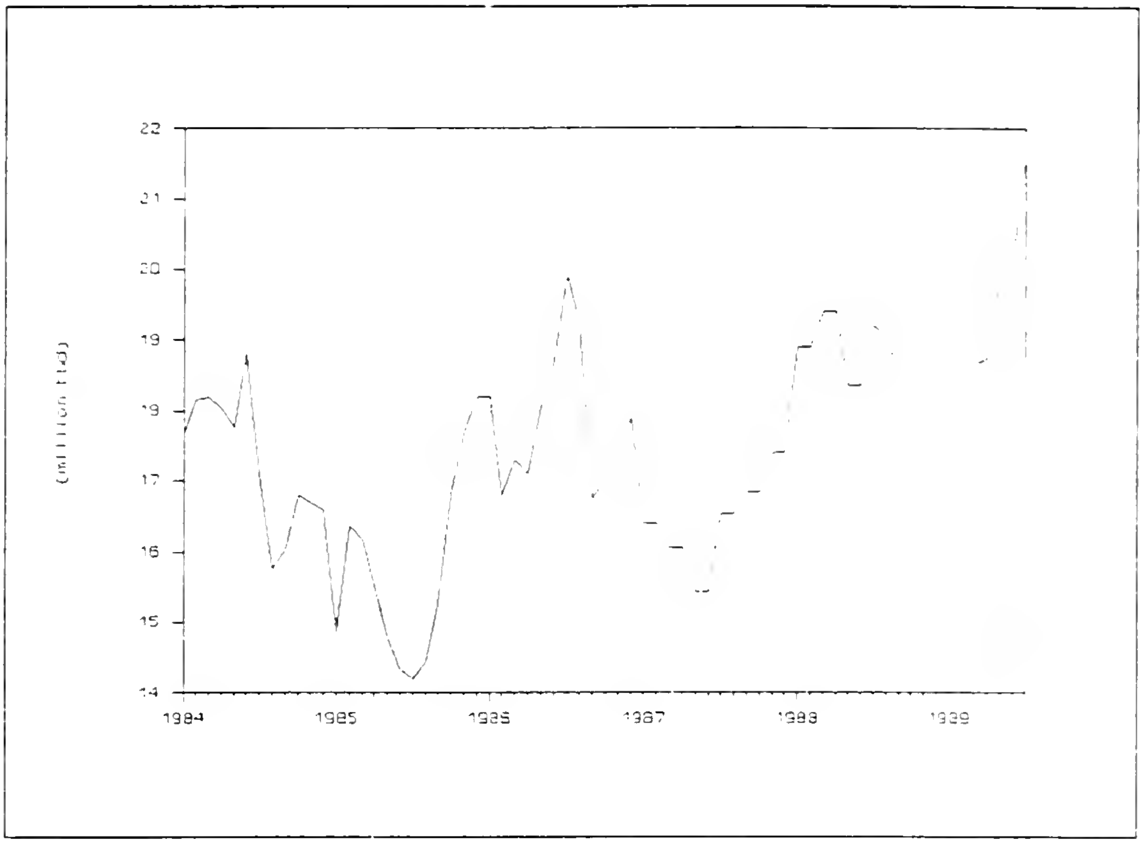

Figure 3.1 OPEC Crude Oil Production

coefficients between the OPEC crude oil supply and futures price series are negative. This result, which is not surprising, tells us that the OPEC supply has a negative effect on oil futures prices, that is, the more the oil production is, the lower are the futures prices. This can be easily explained by the fact that when there is excess supply the price will tend to decline. Second, unlike the relationship between spot price and futures prices shown in the Table 2-2, which shows that the correlation between spot and futures prices falls off from 0.95 for 1-month ahead, progressively declining to 0.62 for 9-month ahead, the cross-correlations increase from 0.465 (in absolute value) for the 1-month-ahead to 0.531 for the 3-month-ahead and 6-month-ahead then drop to 0.528 for 9-month-ahead futures. The correlation between OPEC supply and 3-, 6-, 9-month-ahead futures prices is larger than that between it and 1-month-ahead futures price.

The 1-, 3-, 6- and 9-month-ahead crude oil futures prices are plotted against OPEC production in Figure 3-2 through 3-5, respectively. They demonstrate some interesting movements of futures prices and the OPEC production since 1984. First, the crude oil futures prices move oppositely to that of the OPEC production. Generally speaking, when there is an increase in the production, there is a drop in the futures prices. Second, all the figures show that before the period 1986 and 1987, the gaps between the crude oil futures prices and the OPEC

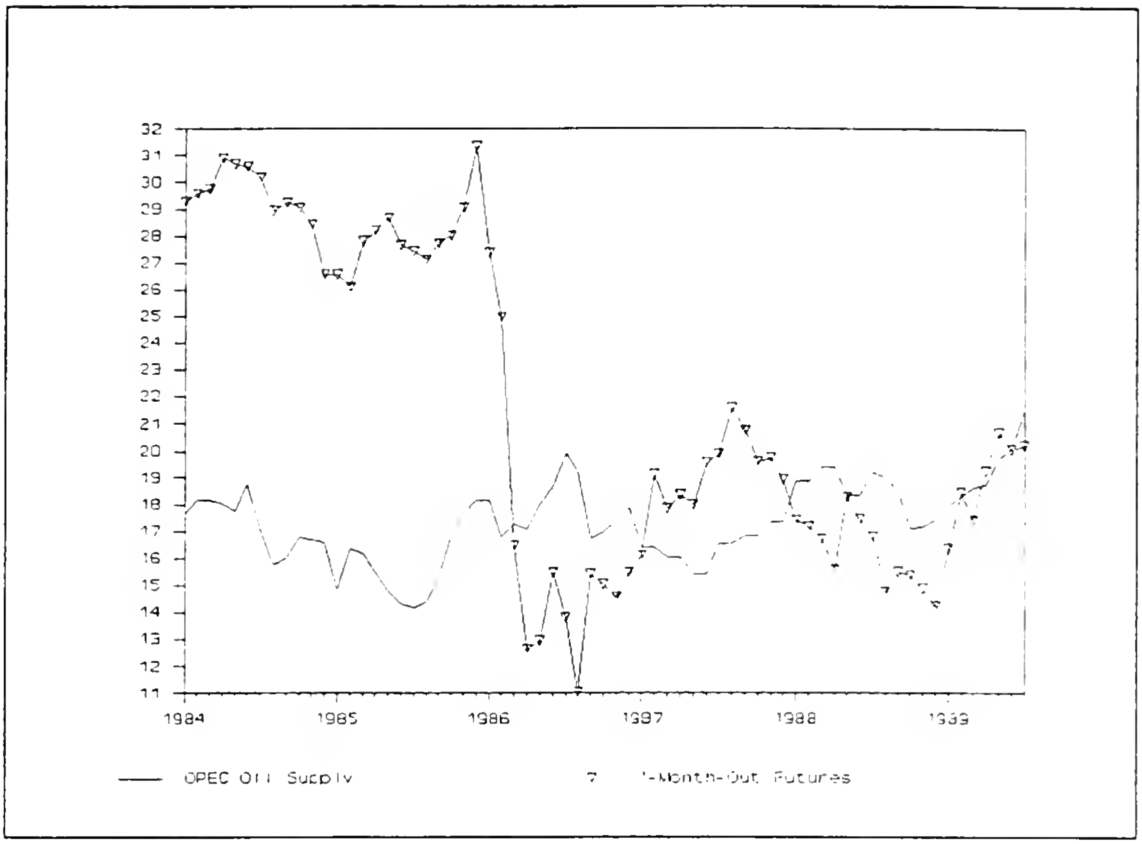

Figure 3.2 Oil Supply & Futures Prices

production are very big. The futures prices falsely signaled the trend of the supply. This is due to the fact that after the oil crisis, people were expecting the oil prices in the futures to increase. From Figure 3-1. we can see clearly that during this mid-1984 and late 1985 periods, the OPEC crude oil production kept declining, too. Therefore traders expected such a negative trend in the production to continue and anticipated another shortage of supply. Second, after mid-1986, the futures prices have been following the OPEC production much more closely. This is because during this time, the investors realized the mistake in their expectation and adjusted it according to the new information. There is another reason for it, that is the oil futures markets are getting more mature and the new technology has been adopted so that people in the market can receive and respond to the new information more quickly. Third, after mid-1985, the futures prices declined a great deal. This was due to the continuous increase in the OPEC crude oil production. Since mid-1985, the OPEC faced strong competition from non-member countries. In order to maintain the market share, OPEC has been increasing its production steadily. This exerted a downward pressure on the futures markets. Observing this fact, the traders became pessimistic about the market. Fourth, from the figures, it can be seen easily that the 3- and 6-month-ahead futures prices more closely mimic the OPEC production. This confirms the "lagged response effects of supply."

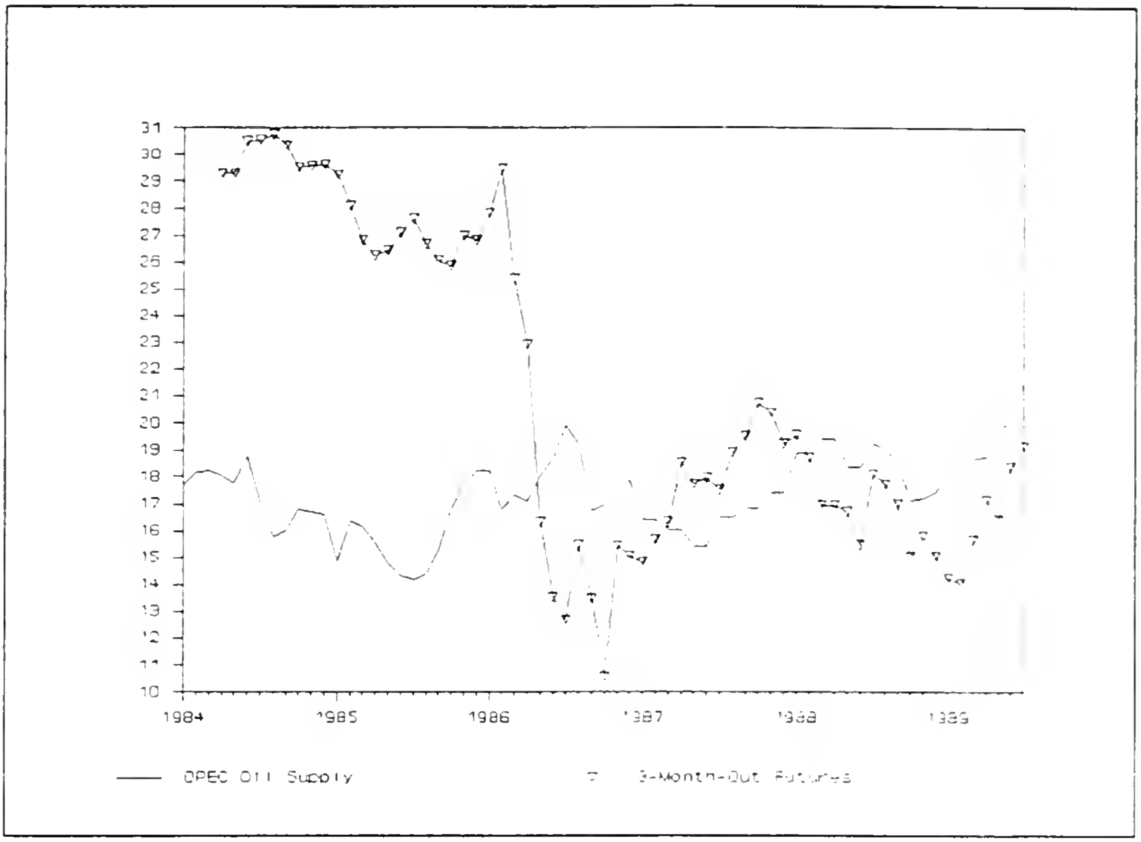

Figure 3.3 Oil Supply & Futures Prices

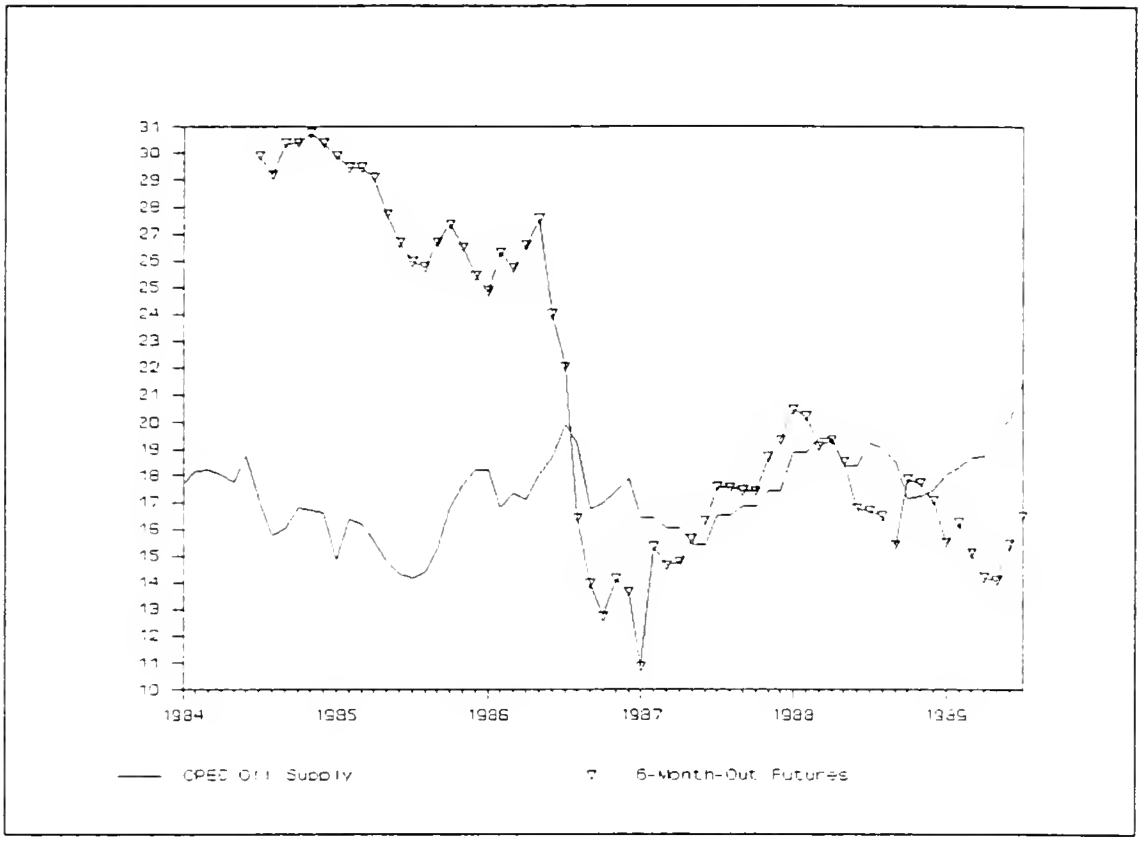

Figure 3.4 Oil Supply & Futures Prices

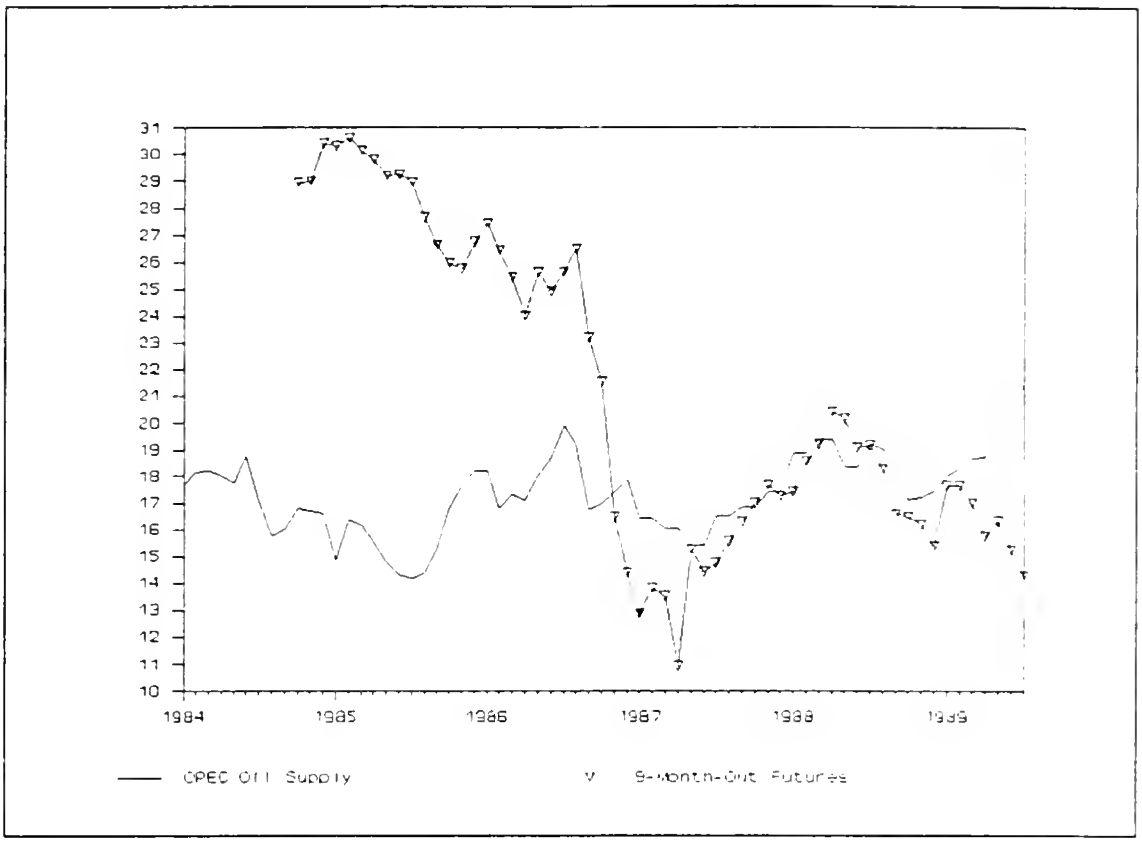

Figure 3.5 Oil Supply & Futures Prices

Another preliminary review of the relationship is to calculate the ratio of futures prices and OPEC production of crude oil in the same month. Table 3-3 presents the mean ratios and standard deviations for these calculations. Again, the lagged response effects of supply is verified. The ratios of 3-, 6- and 9-month-ahead futures prices to the OPEC supply have values closest to unity. This suggests that 3-, 6- and 9-month-ahead futures prices move more closely along with the OPEC oil production than 1-month-ahead futures prices do. However, by looking at the standard deviations, one can also notice that the relationship between the OPEC oil production and 3-, 6- and 9-month ahead futures prices have a higher variance than the ones between the supply and 1-month-ahead futures prices, because the ratio of 1-month-ahead futures price to the OPEC oil production has the smallest standard deviation. This is due to the time span during which people adjust their expectations. The longer the time span, the more likely some new events are to happen during this period, and the more likely that investors readjust their expectations.

Figure 3-6 through 3-9 show the ratios of the OPEC crude oil production and the futures prices for the corresponding time periods. There is a slightly upward shift in the graphs indicating that over time the futures market has been pessimistic about crude oil prices. It is obvious that prior to early 1986, the ratios are well below one. During 1986 and 1987, there were two "over-shoots". There were two peaks

reached by the OPEC production. The futures prices over-adjusted to the increase in the OPEC production. These "over-shoots" have had an impact on the futures markets. They were the turning points when the futures market switched from being optimistic to pessimistic. The market never returned to the level before 1986. After the over-reaction, both investors and the market adjusted. The market was becoming more mature and the traders could respond more instantaneously to the new information by using modern technology. The futures prices then followed the OPEC production more closely. The ratios are much closer to unity, even though there are some fluctuations.

Simple Regressions

In this section, the simple regressions are used to investigate the relationship between the OPEC crude oil production and futures prices are presented and analyzed. Thus the following equations are estimated:

$$FP_{t,1} = \alpha + \beta\ S_t \qquad (3\text{-}1)$$

$$FP_{t,3} = \alpha + \beta\ S_t \qquad (3\text{-}2)$$

$$FP_{t,6} = \alpha + \beta\ S_t \qquad (3\text{-}3)$$

$$FP_{t,9} = \alpha + \beta\ S_t \qquad (3\text{-}4)$$

where

S_t = the OPEC crude oil production at time t;

$FP_{t,j}$ = j-month-ahead futures prices for delivery at time t; for j = 1, 3, 6, 9.

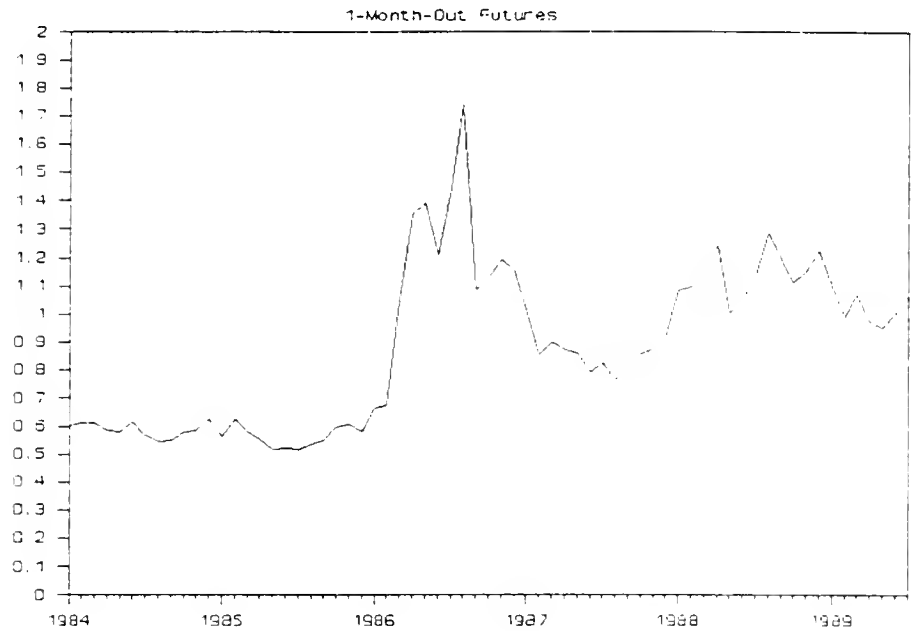

Figure 3.6 Oil Supply /Futures Prices

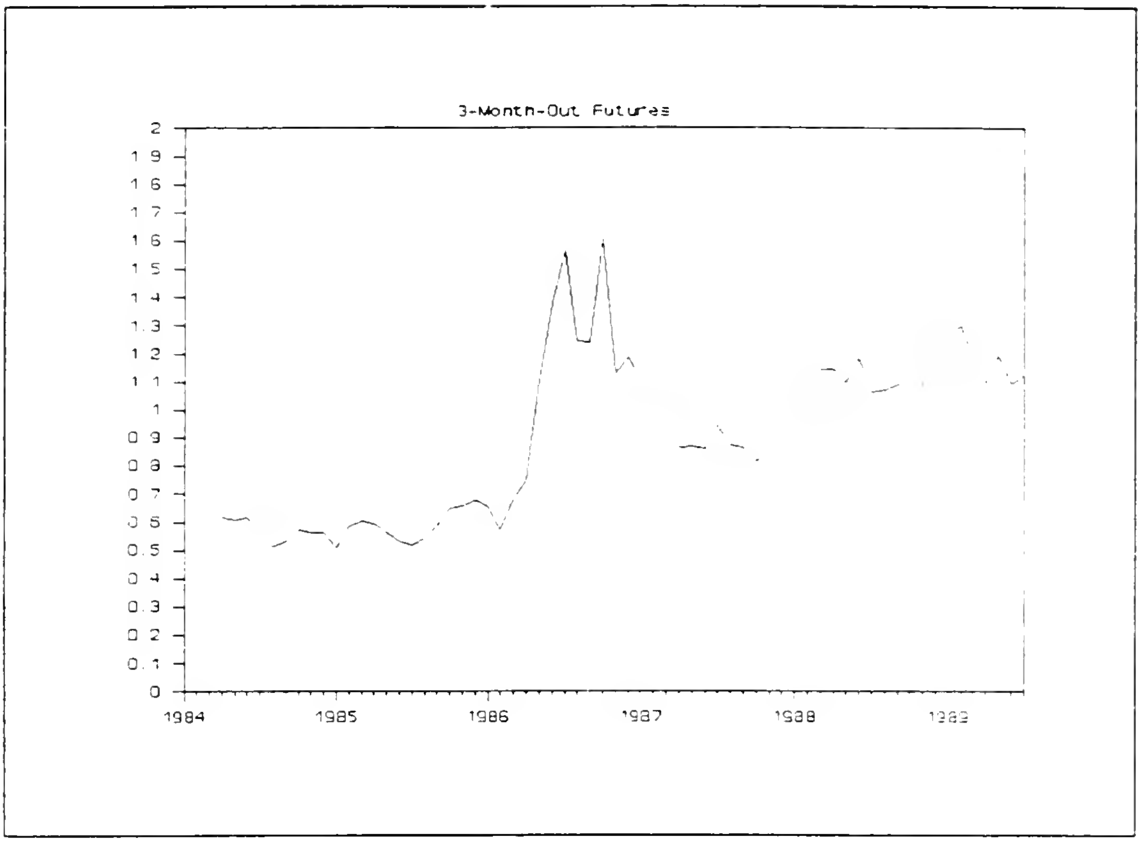

Figure 3.7 Oil Supply /Futures Prices

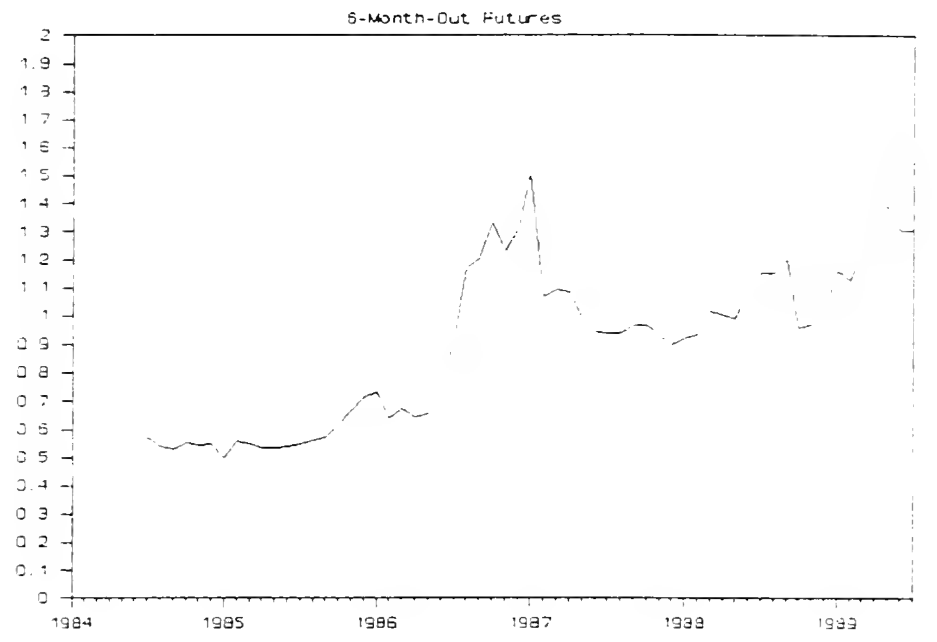

Figure 3.8 Oil Supply /Futures Prices

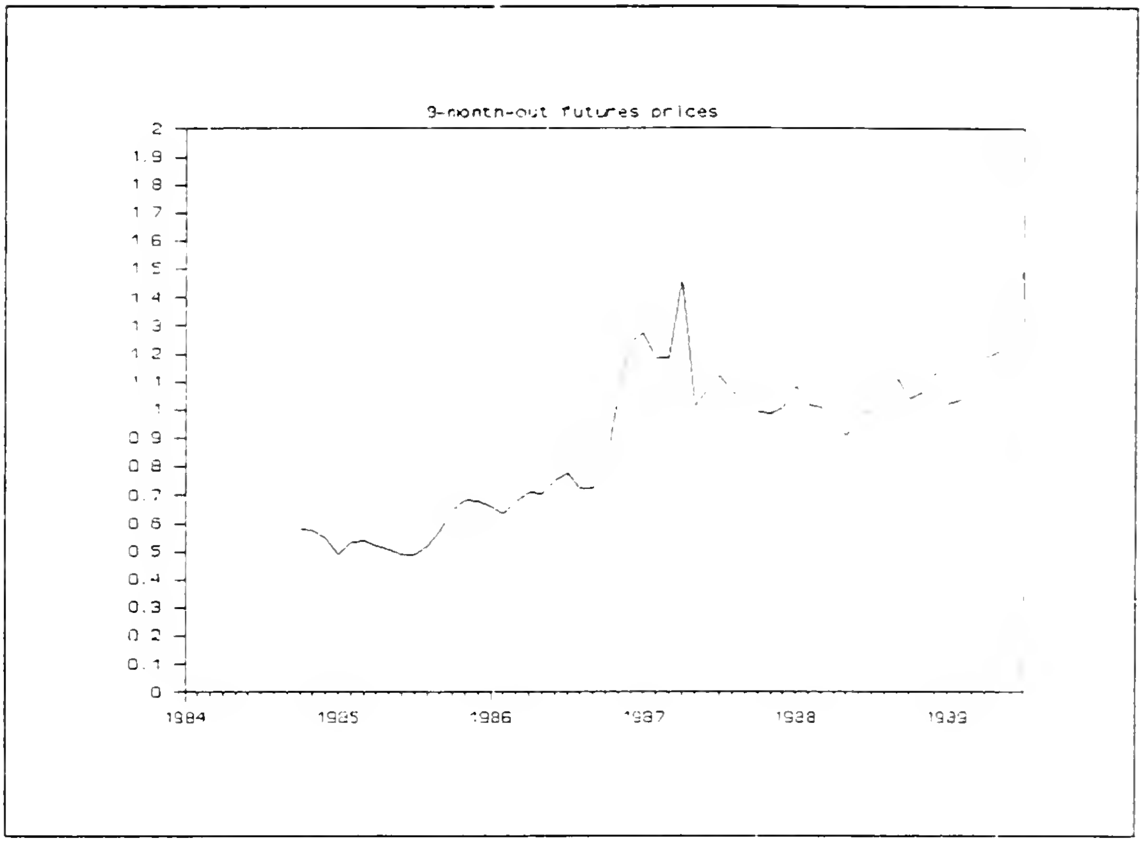

Figure 3.9 OPEC Oil Supply /Futures

Table 3-4 gives the results of this estimation. From this preliminary table, we can obtain the following conclusions. First, the supply variables are statistically very significant in all four equations and the corresponding coefficients are all negative as expected. Second, in terms of R-squared and the standard errors, we can conclude that the equations with 3-, 6- and 9-month-ahead futures prices performed better than the one with 1-month-ahead futures prices. This again verifies the lagged response effects of supply on people's expectations of futures prices.

Basically, however, all four equations may perform poorly. This is because of the fact that the time series under consideration may be nonstatinary. If so, the basic assumptions of simple regression are violated. Therefore, the results from this method can be "spurious" and misleading. In the following sections of this chapter, the nonstationarity of the time series variables will be tested.

Specification Tests

Integration Test

Many macroeconomic variables such as price, supply, demand and so on exhibit nonstatinonarity in levels. Furthermore these variables often appear to be integrated of order one (stationary in the first differences), or to possess unit roots. The integration test is used to determine the nature of the nonstationarity of the economic variables, or in

other words, whether they are stationary in levels or in differences of some order. The co-integration test aims at detecting whether there exists a stable relationship between the levels of two economic variables. In the example here, we try to link the OPEC crude oil production S_t and futures prices and test the relationship between them. If there exists a relationship, then it may be possible that some quantitative effect of the futures prices on the OPEC crude oil production can be made. The theory of the integration test method was discussed in Chapter Two, and hence the details will not be repeated here.

Table 3-5 and 3-6 report the Sargan-Bhagrava (CRDW), Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) test statistics. Table 3-5 shows that for all the series in their levels the unit root hypothesis is not rejected at 99% level of significance. This suggests that even though some results are obtained in the previous section, they are not valid. In order to get these variables to satisfy the normal conditions of simple regression, we need to difference all the variables to see whether the differenced series has a unit root. From Table 3-6 it is apparent that all of the differenced variables reject the hypothesis of unit root at the same level of significance. Thus, all the variables in levels are I(1). This implies that the levels of the OPEC crude oil production and each of four futures prices show similar temporal properties. Therefore, the level of the OPEC crude oil supply and futures

prices are expected to be statistically linked over the long-run, and that the ratios of spot price and futures prices will be constant over time in the long-term.

Cointegration Test

After investigating the fact that both the OPEC crude oil production and futures prices are integrated of the first order, the next step is to examine whether they are also co-integrated. The idea behind the co-integration test is as follows. Suppose two economic variables show nonstationarity do they share the same character of the nonstationary stochastic movement? More precisely, while individual economic time series can be integrated of order one, I(1), certain linear combinations of the series can be stationary or I(0).

It is clear, from table 3-7 below, that no statistics CRDW, DF, ADF is significant at 95 percent confidence level. This implies that no linear combination of the I(1) OPEC crude oil production and the futures prices is possibly stationary and they do not share the same character of the nonstationary stochastic movement. Therefore, we can conclude that the futures prices are not co-integrated with the OPEC crude oil production level.

From the above analysis, we conclude that there is no stable long-run relationship between the OPEC Crude oil production and futures prices. Theoretically, there is no need to go any further. However, as mentioned above, many

researchers make mistakes here. The next two sections are designed to illuminate these mistakes. It is known that the OPEC crude oil production and futures prices are not co-integrated, which suggests that there is no long-run relationship between them. Let us disregard this fact on purpose, and go ahead to implement the popular methods used by many researchers, the Garbade and Silber approach, and the Granger causality test. As it will become clear, controversial results are obtained: one method suggests that futures prices respond to the OPEC crude oil production; the other, on the other hand, suggests that futures prices Granger cause the OPEC oil production.

The Garbade and Silber's Approach

We present the Garbade and Silber approach which leads to the following model of time series behavior:

$$\begin{bmatrix} S_t \\ F_{t,j} \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} 1-\beta_s & \beta_s \\ \beta_f & 1-\beta_f \end{bmatrix} \begin{bmatrix} S_{t-1} \\ F_{t-1,j} \end{bmatrix} + \begin{bmatrix} u_t \\ v_t \end{bmatrix} \qquad (3\text{-}5)$$

where S_t is the logarithm of the OPEC crude oil production in month t and $F_{t,j}$ is the logarithm of the j-month-ahead futures prices for delivery in the same month. The constant terms, α_s and α_f, indicate the trends in the data and any persistent differences between them. The coefficient β_s and β_f reflect the influence of the lagged variable on the current value of the

other variable. The ratio $\beta_f/(\beta_s + \beta_f)$ can be used to examine the relationship between the two variables. If the ratio equals unity (so that $\beta_s = 0$), then it implies that the futures prices always moves in response to the OPEC crude oil production. If the ratio $\beta_f/(\beta_s + \beta_f)$ equals zero (so that $\beta_f = 0$), then the OPEC oil production always adjusts in response to the futures prices. An intermediate value between zero and 1 implies mutual interaction between the two variables.

Equation (3-5) can be solved for $F_t - S_t$ as a function of $F_{t-1,j} - S_{t-1}$:

$$F_{t,j} - S_t = \alpha + \delta(F_{t-1,j} - S_{t-1}) + e_t \qquad (3\text{-}6)$$

where $\alpha = \alpha_f - \alpha_s$, $\delta = 1 - \beta_f - \beta_s$, and $e_t = u_t - v_t$. As can be observed in equation (3-6), δ reflects the speed of convergence between two variables. If δ is small, only a small fraction of the difference between F and S in month t-1 persists to month t. In this case, F and S will converge quickly.

We rearrange equation (3-5) algebraically in the following way, so that it can be estimated via ordinary least squares:

$$\begin{bmatrix} S_t - S_{t-1} \\ F_{t,j} - F_{t-1,j} \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} \beta_s \\ -\beta_f \end{bmatrix} [F_{t-1,j} - S_{t-1}] + \begin{bmatrix} u_t \\ v_t \end{bmatrix} \qquad (3\text{-}7)$$

The estimates β obtained from this equation by using ordinary least squares are summarized in Table (3-8) through Table (3-11). Also given in these tables are the ratio $\beta_f/(\beta_s + \beta_f)$, which show the relative contribution of the OPEC crude oil production to the formation of futures prices, and δ, which measures the rate of the convergence of these two kinds of variables. These tables reveal the following points. First, in all cases, the estimates of β_f's are significantly positive. This finding leads us to conclude that the OPEC crude oil production leads the futures prices in incorporating new information. Second, the estimates of β_s's are also significantly positive, though much smaller than β_f's, which suggests a smaller feedback from the futures market to the OPEC crude oil production. Third, The derived estimates of δ's shown in the tables indicate that only a small amount of the difference between the futures prices and the OPEC oil production in month t-1 persists to month t. This can also be explained by the lagged response effect of production. In this month, the traders are unable to absorb the difference in the relationship between the OPEC oil production and the futures prices which happened last month. Little of the difference persists from last month to this month. However, it may have to be taken into account several months later. Fourth, all the ratios $\beta_f/(\beta_s + \beta_f)$ are well larger than 0.80, which implies that the OPEC production has a strong effect on people's

expectations of the futures prices. This last point strengthens the first point in that not only does the OPEC crude oil production lead the futures prices, but also its influence on the futures prices is significant.

Granger Causality Test

Ignoring the finding that there is no long-run relationship between the OPEC crude oil production and the futures prices, which was based on the co-integration test in the previous two sections, let us implement the Granger test to oil supply and the futures prices anyway.

According to Granger (1969), the simple causal model is

$$S_t = \Sigma_{i=1}^{m} \alpha_{1j} S_{t-j} + \Sigma_{i=1}^{m} \beta_{1j} F_{t-j} + \epsilon_{1t} \qquad (3-8)$$

$$F_t = \Sigma_{i=1}^{m} \alpha_{2j} S_{t-j} + \Sigma_{i=1}^{m} \beta_{2j} F_{t-j} + \epsilon_{2t} \qquad (3-9)$$

where S_t denotes OPEC crude oil production and F_t the futures prices, 1-, 3-, 6- and 9-month-ahead. ϵ_{1t} and ϵ_{2t} are taken to be uncorrelated white-noise series.

S_t is said to cause F_t if some β_{1j}'s are not zero. Similarly F_t is said to cause P_t if some β_{2j}'s are not zero. If both of these events occur, there is a feedback relationship between P_t and F_t. The usual F-test is applied to test the null hypothesis that S_t does not cause F_t corresponding to $\beta_{1j} = 0$ or F_t does not cause S_t corresponding to all $\beta_{2j} = 0$.

We use the restricted least squares method to estimate equation (3-8) and (3-9) by imposing the restrictions $\beta_{1j} = 0$ and $\beta_{2j} = 0$ respectively. Table (3-12) through Table (3-15) summarize the estimation results. The following results emerge. First, it is unclear what kind of relationships exists between the OPEC crude oil production and the futures prices. The restrictions imposed on the equations are statistically significant for different variables. For 1-month-ahead futures price, it seems that the OPEC oil production is Granger caused by the futures prices. The significance level is about 90 per cent. For 3-, and 6-month-ahead futures prices, however, the situation is just the opposite: the futures prices are Granger caused by the OPEC production. The significance level is also about 90 per cent. For 9-month-ahead futures prices, the restrictions on both OPEC production and the futures prices are not statistically significant, a result which suggests that neither the OPEC production Granger causes the futures prices nor the futures prices Granger cause the OPEC production.

Compared with the results presented in the two previous sections, the outcomes obtained in this section are obviously different. The results obtained there with the Garbade and Silber approach indicate that the OPEC oil production has a strong effect on the futures prices. The outcomes in this section, however, suggest that there is no consistent relationship between these two variables. The relationship

between 1-month-ahead futures prices and that between the 3- and 6-month-ahead futures prices are exactly the opposite. The contradiction in findings is due to the nonexistence of any stable long-run relationship between OPEC oil production and the futures prices, a question that needs to be answered in the first step of the proper "two-step" testing procedure for the long run relationship between two variables. If we ignore this step and go ahead to investigate causal relationships , then it is not surprising at all that conflicting results are obtained.

Summary

In this chapter, we have studied the relationships between the OPEC crude oil production and the futures prices. Different methods have been used to examine this relationship. The simple methods, such as graphic and simple regression, suggest that there is an apparent relationship between these two variable. The coefficients of regressing the futures prices on the OPEC oil production is negative, which implies that the OPEC production has a downward pressure on the futures prices. This can also be easily seen by the graphs. With the exception of an unstable period, there was a drop in the futures prices when production increased.

The integration and co-integration tests were then used to investigate the relationship more rigorously. The results from the integration test showed that all the futures prices

and the OPEC oil production were integrated of order one, suggesting that the levels of both the OPEC production and the futures prices were unstable, however, their first order differences are stable. This finding prompted us to employ the co-integration test to examine the hypothesis whether such the nonstationarity of the same order was generated by a similar mechanism. The co-integration test rejected this hypothesis. This means that the nonstationarity of the OPEC production and that of futures prices are not generated by the same mechanism. Therefore, we can conclude that there is no long-run stable relationship between these two variables.

The last two sections of this chapter showed the mistakes that can arise if the fact that there is no long run stable relationship between the two variables is ignored. Most researchers have made this mistake. They usually did not test the existence of the long run relationship before they went to investigate the nature of the relationship with methods such as the Garbade and Silber approach or the Granger causality test. When a long-run relationship does not exist, all the results about the relationship are meaningless. These two sections confirm this argument. We showed conflicting outcomes could arise about the relationship between the futures prices and the OPEC oil production when two different methods were used. The results from the Garbade and silber approach indicated that the OPEC crude oil production strongly influenced the futures prices while those from the Granger

causality test suggested a lack of a consistent relationship. For the 1-month-ahead futures price, the OPEC oil production was Granger caused by futures price. For 3-, and 6-month-ahead futures prices, however, the situation was reversed: the futures prices are Granger caused by the OPEC production.

Table 3-1

Selected Statistics for
OPEC Crude Oil Supply Futures Price

Series	Mean	S.D.	Max.	Min.
Supply	17.83	1.82	22.46	14.46
Futures				
1-Month-ahead	21.39	5.98	31.35	11.04
3-Month-ahead	21.04	5.96	30.73	10.58
6-Month-ahead	20.93	5.95	30.73	10.86
9-Month-ahead	21.05	5.85	30.62	10.92

Table 3-2

Cross-Correlations for
OPEC Crude Oil Supply and Futures Price

Variable	Supply	1-Month	3-Month	6-Month	9-Month
Supply	1.000	-0.465	-0.531	-0.531	-0.528
1-Month-ahead		1.000	0.872	0.700	0.700
3-Month-ahead			1.000	0.854	0.732
6-Month-ahead				1.000	0.889
9-Month-ahead					1.000

Table 3-3

Selected Statistics for OPEC Crude Oil
Supply and Futures Price Ratios

Ratio to Supply:	Mean	S.D.	Max.	Min.
Futures				
1-Month-ahead	1.23	0.42	1.94	0.57
3-Month-ahead	1.21	0.43	1.97	0.62
6-Month-ahead	1.21	0.43	2.01	0.66
9-Month-ahead	1.21	0.43	2.04	0.66

Table 3-4

Regression Coefficients for 1-, 3-, 6- and 9-Step Ahead Crude Oil Futures Prices on OPEC Crude oil Production

Variable	Dependent variable			
	F_1	F_3	F_6	F_9
Constant	48.91* (7.53)	57.28* (8.32)	50.42* (8.18)	49.86* (8.02)
S	-1.54* (-4.24)	-1.67* (-4.93)	-1.66* (-4.81)	-1.61 (-4.66)
1st-Order Autocorrelation	0.90	0.88	0.88	0.90
R^2	0.22	0.28	0.28	0.28
$\overline{R}^2$	0.20	0.27	0.27	0.27
D-W	0.17	0.18	0.20	0.16
Std. Error	5.37	5.09	5.08	5.01

Table 3-5

Results of Integration Tests for OPEC Crude Oil Supply and Futures Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
S	0.231	-1.64	-1.76
FP1	0.094	-1.62	-1.72
FP3	0.077	-1.52	-1.72
FP6	0.060	-1.36	-1.69
FP9	0.564	-1.03	-1.49

Table 3-6

Results of Integration Tests for First Order Differenced OPEC Crude Oil Supply and Futures Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
Δ S	1.72	-6.90	-5.73
Δ FP1	1.65	-6.61	-4.90
Δ FP3	1.71	-6.69	-4.80
Δ FP6	1.72	-6.55	-4.24
Δ FP9	1.80	-6.67	-4.03

Table 3-7

Results of Cointegration Tests for OPEC Crude Oil Supply and Futures Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 95%: -3.17)
Case 1	0.087	-1.36	-1.44
Case 2	0.076	-1.24	-1.57
Case 3	0.047	-1.01	-1.50
Case 4	0.055	-0.76	-1.11

Key:
Case 1: OPEC Oil Supply vs 1-Month-Ahead Futures Price
Case 2: OPEC Oil Supply vs 3-Month-Ahead Futures Price
Case 3: OPEC Oil Supply vs 6-Month-Ahead Futures Price
Case 4: OPEC Oil Supply vs 9-Month-Ahead Futures Price

Table 3-8

Estimated Coefficients from the Garbade and Silber Approach: OPEC Oil Supply and 1-Month-Ahead Futures Prices

Parameter	Period 1984M1 - 1989M7
β_s	0.157 (6.886)
β_f	0.797 (34.62)
$\beta_f/(\beta_s+\beta_f)$	0.835
δ	0.049

Table 3-9

Estimated Coefficients from the Garbade and Silber Approach: OPEC Oil Supply and 3-Month-Ahead Futures Prices

Parameter	Period 1984M1 - 1989M7
β_s	0.171 (7.674)
β_f	0.782 (35.02)
$\beta_f/(\beta_s+\beta_f)$	0.821
δ	0.047

Table 3-10

Estimated Coefficients from the Garbade and Silber Approach: OPEC Oil Supply and 6-Month-Ahead Futures Prices

Parameter	Period 1984M1 - 1989M7
β_s	0.174 (7.437)
β_f	0.778 (32.77)
$\beta_f/(\beta_s+\beta_f)$	0.817
δ	0.048

Table 3-11

Estimated Coefficients from the Garbade and Silber Approach: OPEC Oil Supply and 9-Month-Ahead Futures Prices.

Parameter	Period 1984M1 - 1989M7
β_s	0.178 (7.150)
β_f	0.774 (31.31)
$\beta_f/(\beta_s+\beta_f)$	0.813
δ	0.048

Table 3-12

Causality On OPEC Crude Oil Production and 1-Month-Ahead Futures Prices

Independent	Dependent Variable	
	S_t	F_t
S_{t-1}	1.19 (8.78)	0.09 (0.29)
S_{t-2}	-0.27 (-1.39)	0.01 (0.21)
S_{t-3}	-0.08 (-0.39)	-0.37 (-0.83)
S_{t-4}	0.20 (0.98)	0.05 (0.11)
S_{t-5}	-0.08 (-0.39)	-0.24 (-.55)
S_{t-6}	0.05 (0.40)	0.55 (1.90)
F_{t-1}	0.10 (1.60)	1.06 (7.66)
F_{t-2}	-0.17 (-1.71)	-0.01 (-.46)
F_{t-3}	-0.00 (-0.01)	-0.08 (-.36)
F_{t-4}	-0.01 (-0.13)	0.16 (0.73)
F_{t-5}	0.21 (2.10)	-0.13 (-.61)
F_{t-6}	-0.13 (-2.00)	-0.10 (-.10)

Table 3-12--continued

R^2	0.998	0.994
$\overline{R}^2$	0.997	0.993
F	1.866	1.469
PROB > F	0.106	0.217

Table 3-13

Causality On OPEC Crude Oil Production and 3-Month-Ahead Futures Prices

Independent	Dependent Variable	
	S_t	F_t
S_{t-1}	1.10 (7.54)	0.66 (2.26)
S_{t-2}	-0.10 (-.44)	-1.07 (-2.43)
S_{t-3}	-0.23 (-.97)	0.59 (1.29)
S_{t-4}	0.22 (1.05)	0.10 (0.24)
S_{t-5}	-0.10 (-0.48)	-0.60 (-1.50)
S_{t-6}	0.09 (0.69)	0.38 (1.44)
F_{t-1}	-0.08 (-1.06)	1.18 (8.12)
F_{t-2}	0.01 (0.12)	-0.18 (-.80)
F_{t-3}	0.18 (1.59)	-0.02 (-.08)
F_{t-4}	-0.00 (-0.03)	-0.09 (-.40)
F_{t-5}	-0.15 (-1.31)	0.03 (0.12)
F_{t-6}	0.04 (0.49)	0.02 (0.16)

Table 3-13--continued

R^2	0.998	0.995
$\bar{R}^2$	0.998	0.993
F	1.173	1.660
PROB > F	0.337	0.163

Table 3-14

Causality On OPEC Crude Oil Production and
6-Month-Ahead Futures Prices

Independent	Dependent Variable	
	S_t	F_t
S_{t-1}	1.15 (7.79)	-0.23 (-0.93)
S_{t-2}	-0.23 (-1.04)	0.05 (0.15)
S_{t-3}	-0.16 (-.71)	-0.03 (-0.09)
S_{t-4}	0.30 (1.32)	0.76 (2.05)
S_{t-5}	-0.31 (-1.38)	-0.95 (-2.54)
S_{t-6}	0.26 (1.75)	0.44 (1.77)
F_{t-1}	0.15 (1.70)	1.17 (7.81)
F_{t-2}	-0.18 (-1.37)	-0.06 (-0.26)
F_{t-3}	0.05 (0.37)	-0.01 (-0.05)
F_{t-4}	-0.13 (-1.00)	-0.32 (-1.49)
F_{t-5}	0.28 (2.09)	0.14 (0.64)
F_{t-6}	-0.16 (-1.81)	0.04 (0.26)

Table 3-14--continued

R^2	0.998	0.996
$\bar{R}^2$	0.998	0.995
F	1.158	1.930
PROB > F	0.347	0.109

Table 3-15

Causality On OPEC Crude Oil Production and 9-Month-Ahead Futures Prices

Independent	Dependent Variable	
	S_t	F_t
S_{t-1}	1.30 (8.68)	0.04 (0.15)
S_{t-2}	-0.48 (-2.04)	0.28 (0.70)
S_{t-3}	-0.05 (-.22)	-0.06 (-0.17)
S_{t-4}	0.28 (1.30)	-0.53 (-1.48)
S_{t-5}	-0.28 (-1.28)	0.23 (0.63)
S_{t-6}	0.23 (1.60)	0.08 (0.36)
F_{t-1}	-0.06 (-0.62)	0.99 (6.23)
F_{t-2}	0.19 (1.43)	0.21 (0.95)
F_{t-3}	-0.15 (-1.15)	-0.10 (-.44)
F_{t-4}	-0.01 (-0.08)	-0.29 (-1.29)
F_{t-5}	0.12 (0.88)	0.08 (0.34)
F_{t-6}	-0.09 (-0.95)	0.07 (0.44)

Table 3-15--continued

R^2	0.998	0.996
$\bar{R}^2$	0.998	0.995
F	0.640	1.154
PROB > F	0.697	0.349

CHAPTER IV
SPOT PRICES AND OPEC CRUDE OIL SUPPLY

Introduction

The world petroleum market, which had been a buyer's market for a decade, was rapidly transformed into a seller's market, enabling the oil-producing countries and the national oil companies of these nations to secure greater control over their market. The abrupt increases in the world crude oil price in 1973-1974 or 1979-1980 were mainly caused by the OPEC's supply interruptions to the world supply of oil. Even though the supply shortfalls were comparatively small, they resulted in very large increases in the price of oil. Sudden price jumps are disruptive. They are harder to accommodate in the balance of payments. They raise inflationary problems in an aggravated form. These economic losses are not easy to quantify, but available estimates indicate that they have been very large. Calculations by the OECD and others suggest that the 1979-1980 oil price shock caused world production by 1982 to be about 6 percent lower than it otherwise would have been, amounting to a cumulative loss in output over the period of about $1 trillion. That loss, it should be emphasized, is independent of the oil-importing countries' loss in income from the deterioration in their terms of trade. Initially, the

1979-1980 oil price jump transferred about $150 billion from oil importers to oil exporters, an amount that diminished in subsequent years as the volume of oil consumption declined and the price fell. Unlike these terms-of-trade income transfers, the large losses of output in the oil importing countries caused by the disruptions had no counterpart gains for the oil exporters. Quite the contrary, the reduction in economic output of the oil importers and the accelerated replacement of oil-intensive equipment have indeed reduced the medium- and long-term demand for oil, generating steady downward pressure on its price with eventual economic costs to oil exporters as well.

The supply interruptions can be explained by the theory of economic rents. Since sixty percent of the world oil reserves and three fourths of the present excess productive capacity are located in the Persian gulf region, the supply side of the oil market is not very competitive. Therefore, economic rents arise. By restricting supply to maintain or increase their rents, oil exporters tend to ignore underlying supply-demand realities, thereby, creating market problems.

Since an abrupt jump of oil price is very disruptive for many countries including the United States, it is very important to be impervious to supply interruptions. Great reliance on OPEC oil not only will tend to raise world oil prices but also will make the importing nations more vulnerable to the supply disruption, which is plausible given

the turmoil of the Middle East. As we all know, raising oil prices sharply and suddenly with a supply contraction transfers wealth from the oil-importing to oil-exporting nations. In addition, there are sizable indirect costs. A large supply disruption of, say, 10 million barrels per day could reduce U.S. gross national product by as much as 7 percent. Also, sudden increase in oil prices tend to make more difficult economic management. There is, furthermore, a cumulative problem. If oil-exporting countries are slow to expand their own imports and accumulate large liquid balances in dollars and other currencies, their various portfolio adjustments can have potentially startling effects on the capital account, balance of payments, and exchange rates.

Since the supply interruptions interfere with an economy to a great deal, the important questions we should ask are: Are the supply interruptions, which have occurred in the past, likely to recur in the future? Would the economic costs of disruption, proportionately, be similar in the future? Or would the learning experience of the past make any difference. In order to answer these questions, it is important to study the relationship between the OPEC oil supply and the prices, in particular, if the prices follow the OPEC oil supply. Even though, the prices and supply are most likely unstable, they may share the same nature of the nonstationarity. Furthermore, certain linear combination of these variables may be stable. If the linear combination fails to be stable, we then should

introduce a new model to investigate the relationship. This chapter is aimed at studying these issues. The rest of this chapter is arranged in the following way.

First we obtain some information about the data with simple methods such as statistical tabulations and graphics. Next, we present the results from simple regressions. By implementing integration and cointegration tests, we then investigate the characteristics of the time series under consideration. Since crude oil prices and OPEC oil supply are found not to be cointegrated, we introduce a "self-adaptive" model to study the effects of the supply interruptions in the next section. Finally we conclude the chapter with a short comment.

Data Analysis

There are three kinds of crude oil prices prevailing in the market: Brent, OPEC spot and WTI (West Texas Intermediate). Due to the difficulty of collecting data, the sample of our data is from January 1985 to July 1989. In this section, some preliminary methods, such as, the graphic, basic statistical analysis, are used to get some ideas about the time series we are interested in.

The movement of the OPEC spot price and production were depicted in the Figure 2-1 and Figure 3-1, respectively. Figure 4-1 and figure 4-2 show the monthly values for the Brent crude oil price and WTI price series since 1985, respectively.

Several things are apparent from the figures. First, the crude oil prices have had a tendency to fall. This is due to the fact that the OPEC oil production has been increasing steadily in this period. Secondly, this decline has been irregular. There was a peak in January of 1986, then the prices declined dramatically. Starting from mid-1986, they increased continuously until mid- or late-1987. In the period mid-1987 to 1988, they kept falling. After a small recovery followed until the first season of 1988, they dropped again. However, since 1989, they have been increasing, even though there were some fluctuations. The movement of the prices will become clear if they are tied with the OPEC crude oil production, which can be seen in Figures 4-3 through 4-5. Before examining these graphs, let us look at some basic statistics about the OPEC oil production and the prices.

Table 4-1 provides the mean, standard deviation, maximum, and minimum of these variables: the OPEC oil production and Brent, OPEC spot and WTI prices. The cross-correlation coefficients for these series are shown in Table 4-2. As shown in the table 4-1, the mean of the OPEC crude oil production from January 1985 through July 1989 is 18.15 million barrels per day, which is slightly higher than 17.83 million barrels per day, the mean for the period from January 1984 to July 1989, which implies that the OPEC oil production has been going up. The means of Brent, OPEC spot and WTI prices are 18.69, 17.46, and 19.41 $/bbl respectively.

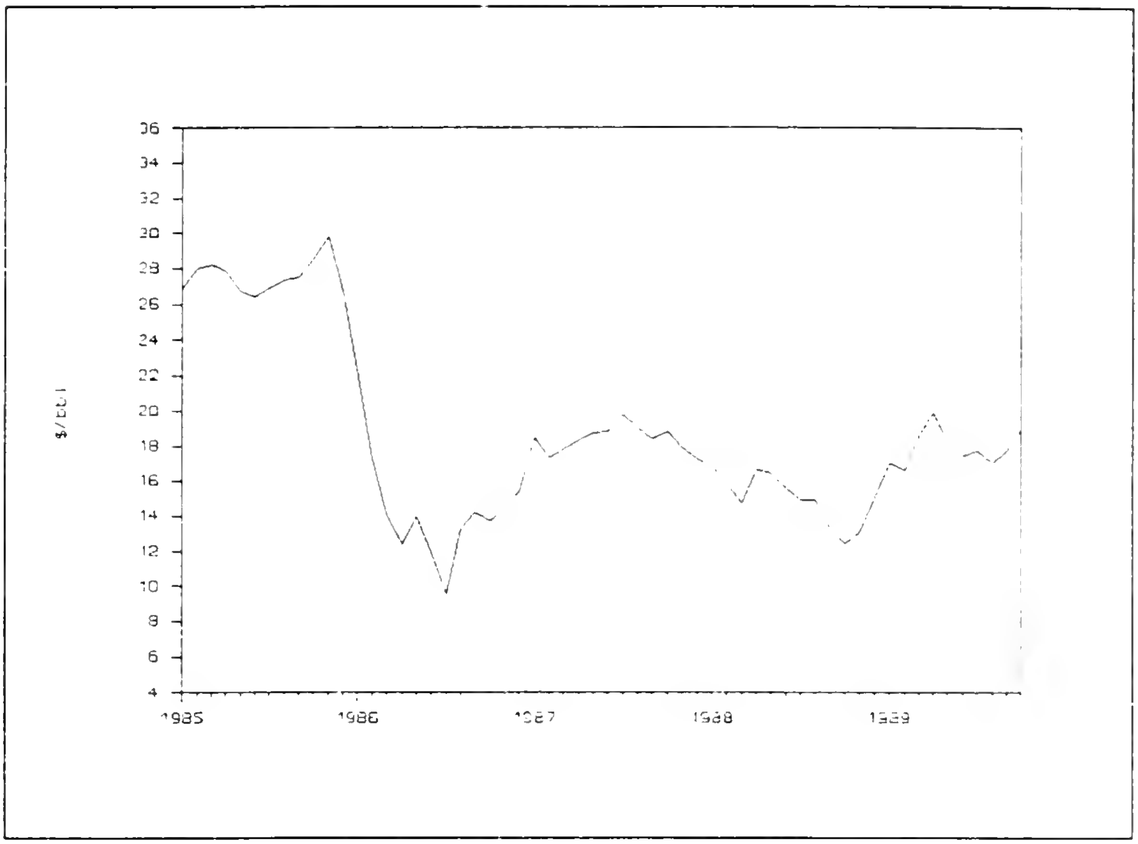

Figure 4.1 Brent Oil Prices

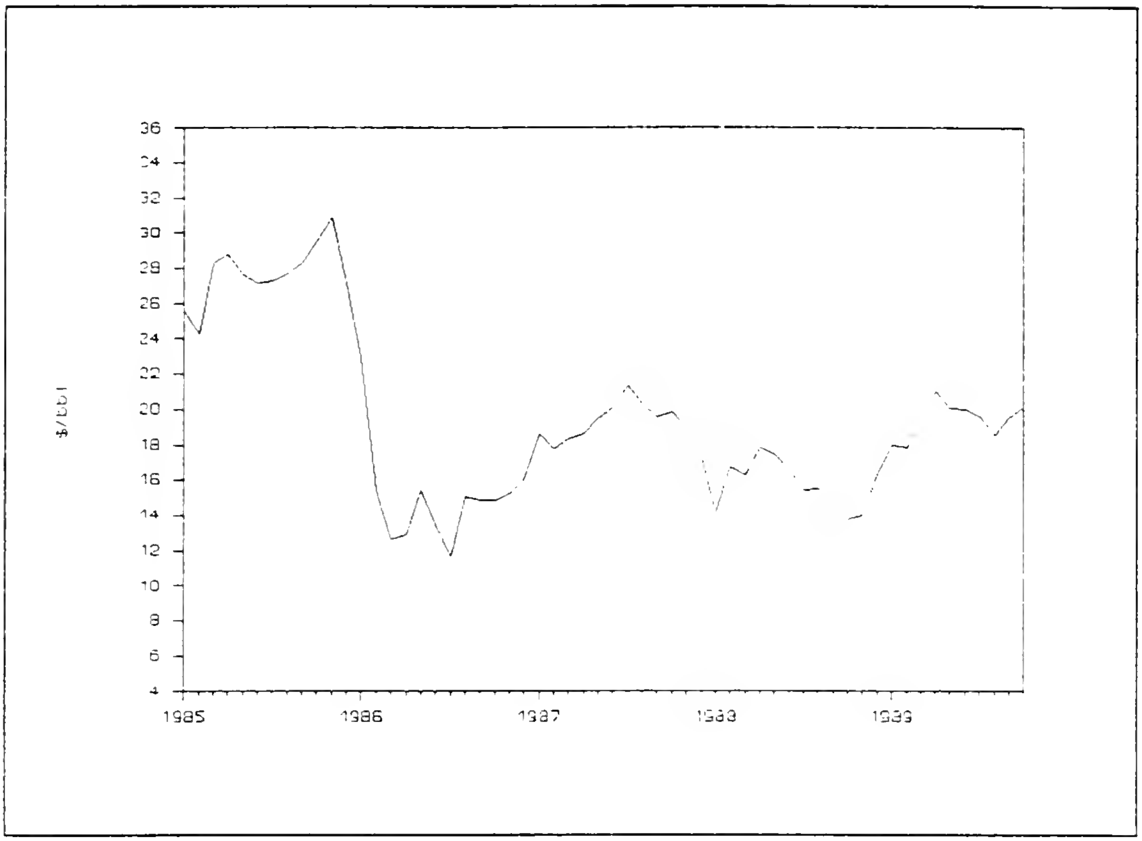

Figure 4.2 WTI Oil Prices

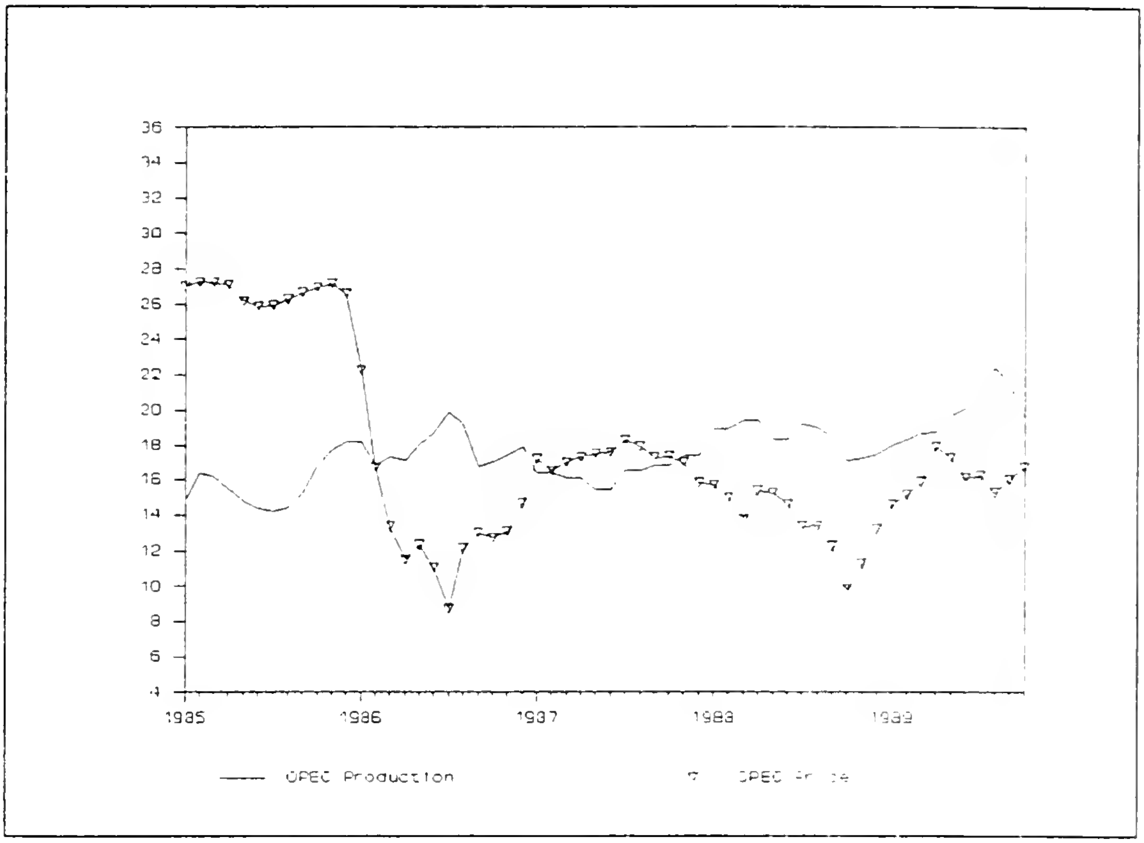

Figure 4.4 OPEC Supply & Spot Price

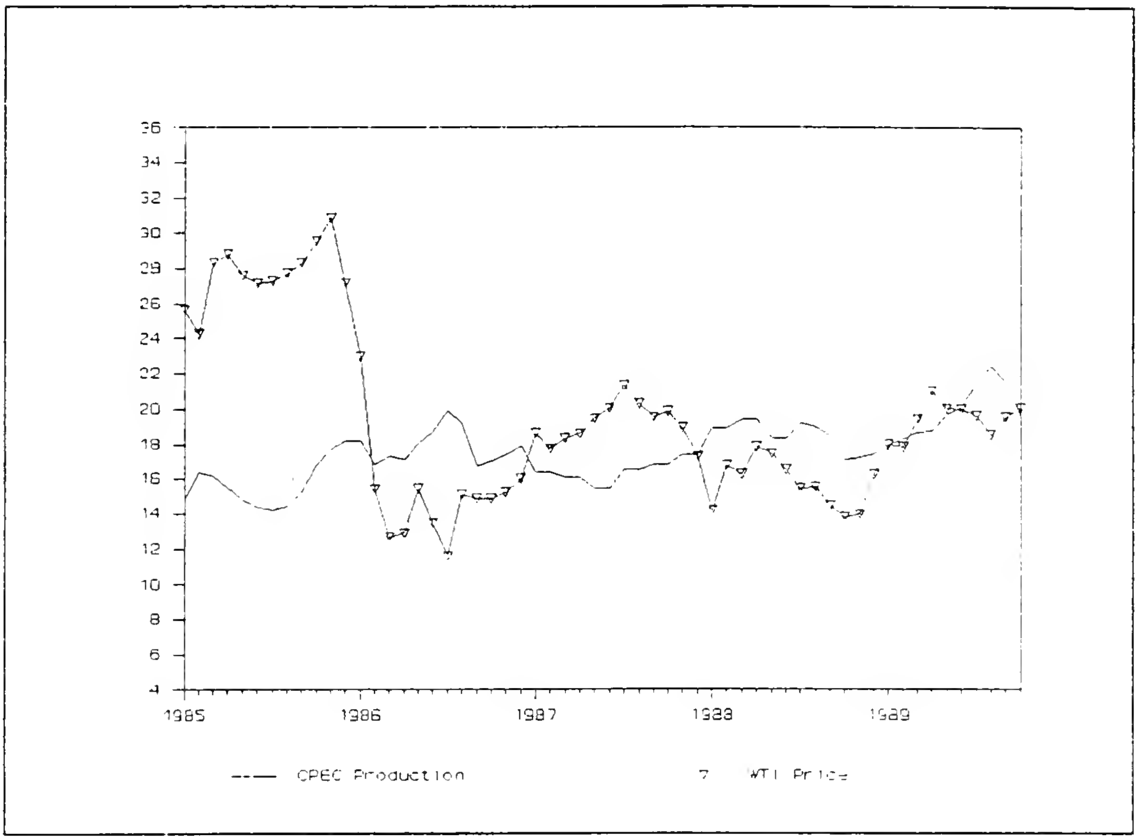

Figure 4.5 OPEC Supply & WTI Price

Figure 4.3 OPEC Supply & Brent Price

There are two interesting points about the Table 4-2, which are more or less the same as in the case of the futures prices. First, it shows that the correlation coefficients between the OPEC crude oil supply and the price are negative. This result, which is not surprising, tells us that the OPEC supply had a negative effect on the prices. Second, the correlation between OPEC production and OPEC spot price was highest, followed by that with the Brent price, and then by that WTI price. Among the correlations coefficients between the OPEC production and the prices, for the spot price, it is -0.59, for Brent, it is -0,54, for WTI, it is -0.46. Finally, the three prices seemed to be very highly correlated, the coefficients were 0.99 between the Brent price and OPEC spot, 0.98 between Brent and WTI, and 0.97 between OPEC spot and WTI.

The Brent price, OPEC spot and WTI prices are plotted against the OPEC production in Figures 3-3 through 3-5, respectively. They demonstrate that the movements of the prices and the OPEC production since 1985, which show some interesting points. First, it is clear that the crude oil prices move oppositely to the OPEC production. Generally speaking, when there was an increase in OPEC production, there was a drop in the prices, or when there was a drop in the production, there was an increase in the prices. Second, all the figures show that before 1986, the gaps between the crude oil prices and the OPEC production were very big. This is due

to the lagged effect of the decrease in the OPEC production before 1985. From Figure 3-1 we can see clearly that in mid-1985, there was a big drop in the OPEC crude oil production. Since 1986, there has been a much clearer negative relationship between the prices and production. the prices have been following the OPEC production very closely through an opposite movement. This phenomena indicates that the oil market is getting more mature than before.

Another preliminary way to view the relationship is to calculate the ratio of prices divided by the OPEC production of crude oil for the same month. Table 4-3 presents the mean ratios and standard deviations for these calculations. Again, it is verified that the OPEC price is correlated with the OPEC oil production most closely, because the mean is 1.00. It also has the biggest standard derivation.

Figures 4-6 through 4-8 show the ratios of the OPEC crude oil production and the prices for the corresponding time periods. There is a slightly upward trend in the graphs indicating that, over time, OPEC oil production has been moving up and the price has been going down. It is obvious that prior to early 1986, the ratios are well below one, because this period was still in the 1985's oil crisis. There were several "over-shoots" after 1986, corresponding to the big increase in the OPEC oil production and dragged response in the prices.

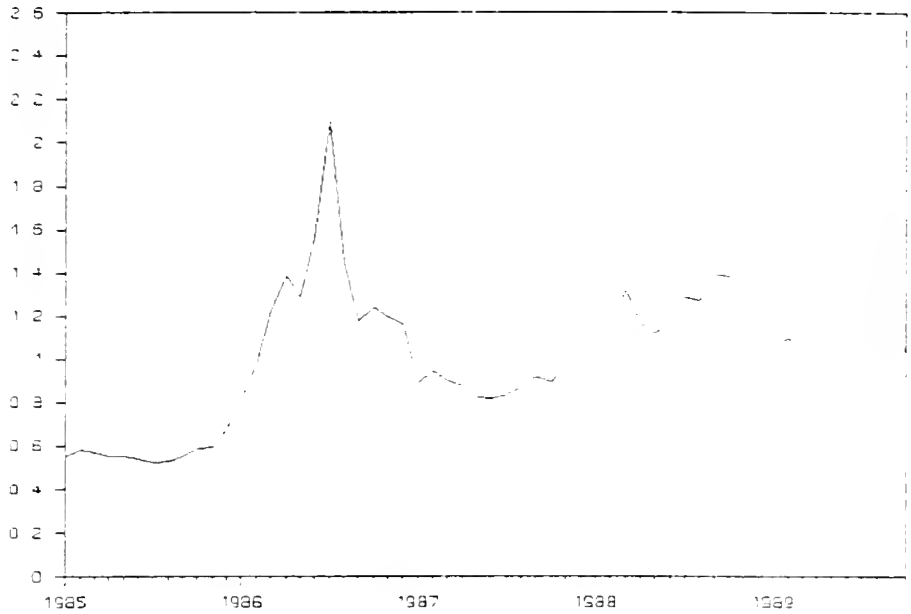

Figure 4.6 OPEC Supply & Brent Price

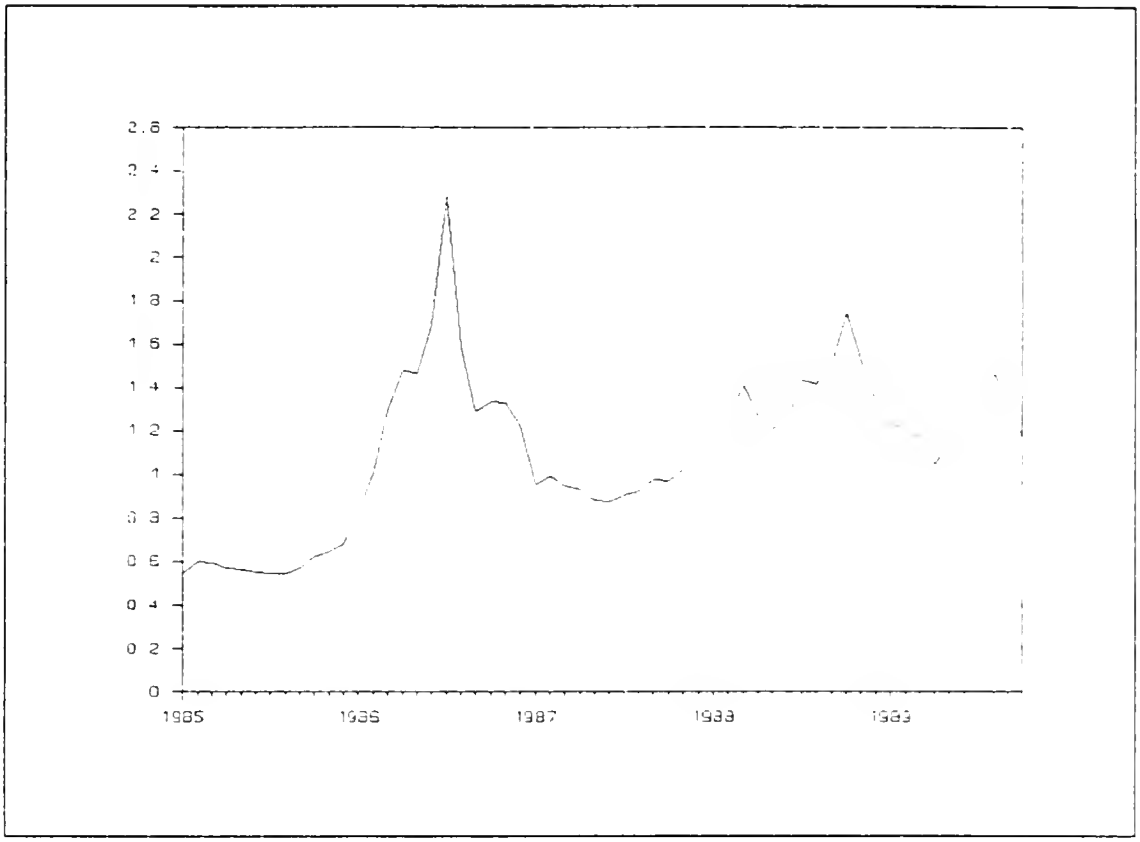

Figure 4.7 OPEC Supply / Spot Price

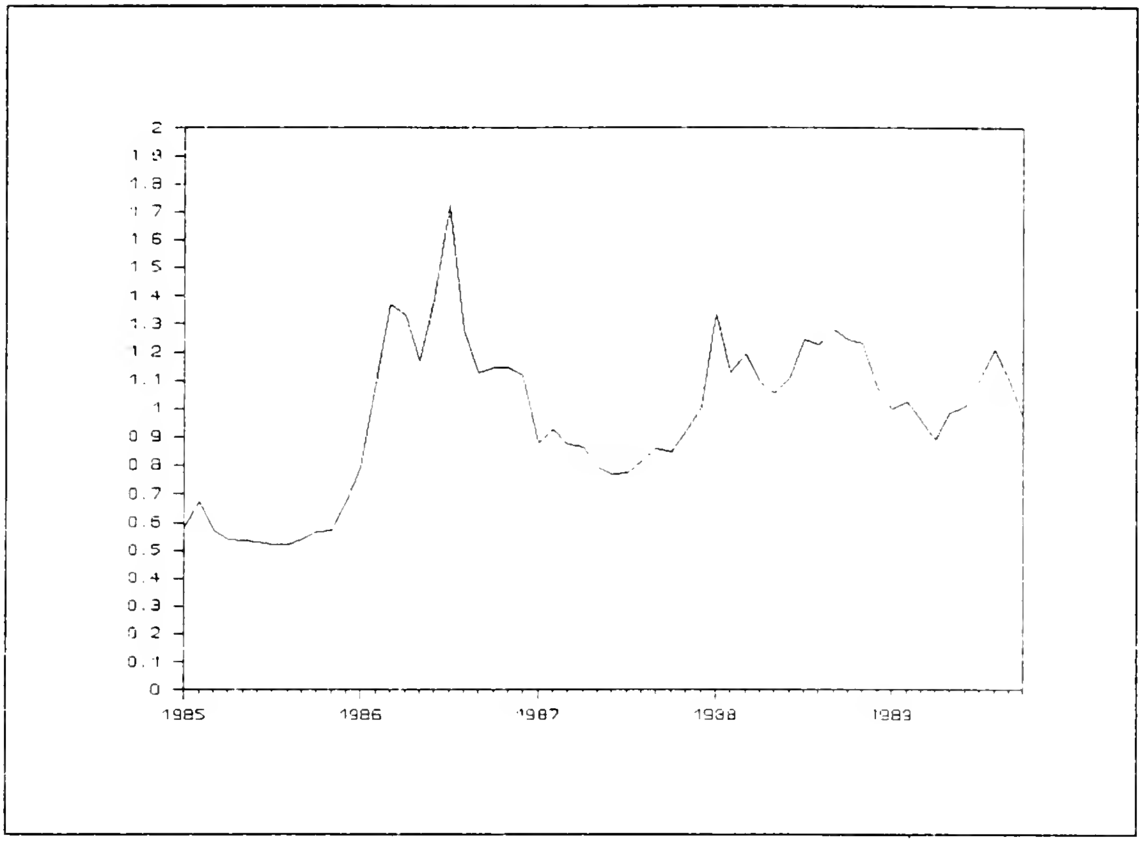

Figure 4.8 OPEC Supply / WTI Price

Simple Regressions

In this section, we specify simple regression methods to investigate the relationship between the OPEC crude oil production and the prices and analyze the results. The following models are estimated:

$$B_t = \alpha + \beta S_t \qquad (4\text{-}1)$$

$$P_t = \alpha + \beta S_t \qquad (4\text{-}2)$$

$$W_t = \alpha + \beta S_t \qquad (4\text{-}3)$$

where

S_t = the OPEC crude oil production at time t;

B_t = the Brent price;

P_t = the OPEC crude oil spot price;

W_t = the WTI price.

Table 4-4 gives the estimation results. First, the coefficient β is statistically very significant in all the three equations and the corresponding coefficients are all negative as expected. Second, based on R-squared and the standard error, we conclude that the equation with the OPEC spot price performs better than the other two. This again verifies the conclusion obtained in last section that the OPEC spot price is correlated with the OPEC supply most closely.

In the following sections of this chapter, we are going to test the nonstationarity of the time series variables, a fact which can not be ignored as stated earlier.

Specification Tests

We implement the integration and co-integration test to determine the stationarity and the nature of the stochastic movement of the time series.

Integration Test

The details of integration test are discussed in Chapter Two. Therefore, we just present the test results for the two variables in the following tables.

Table 4-5 and 4-6 report the Sargan-Bhagrava (CRDW), Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) test statistics. Table 4-5 shows that all the series in their levels are unstable at 99% level of significance. In order to get these variables to satisfy the normal conditions of simple regression, we differenced all the variables and then carried out the tests. From Table 4-6, it is apparent that all of the differenced variables are stable at the same level of significance. Thus, all the variables are integrated as I(1). This implies that the levels of the OPEC crude oil production and each of the three prices show similar temporal properties.

Cointegration Tests

After the fact that both the OPEC crude oil production and futures prices are found to be integrated of the first order, the next step is to examine whether they are also co-integrated. The definitions of co-integrated test has been

stated before, so we are not going to repeat it here, and we only give the results as follows.

It is clear, from the table 4-7 below, that none of the statistics CRDW, DF, ADF are significant at 95 percent confidence level. This implies that no linear combination of the integrated at level one variables, OPEC crude oil production and the prices, is possibly stationary. Thus they do not share the same character of the nonstationary stochastic movement. Therefore, it can be concluded that the prices are not co-integrated with the OPEC crude oil production level.

From the above analysis, we can conclude that there is no long-run relationship between the OPEC Crude oil production and prices. By looking at the figures presented in section 4.2, 1 may argue that the period before 1986 is somewhat unstable. Therefore, if this period is removed from the sample, the results may be improved. The answer to this is no. In Appendix One, we will show out that even with the sample reduced from 1985 - 1989 to 1986 - 1989, the prices are still not co-integrated with the OPEC production. Therefore, a "self-adaptive" model will be presented in the next section to describe the movement of the crude oil prices.

<u>The Self-Adaptive Model</u>

Since there is no long-run stable relationship between the spot price and the OPEC production, the OPEC production

should not be included in any models which investigate the behavior of the prices. In this section, a "self-adaptive" model is proposed to describe the price movement. The idea behind this model is that the price itself may contain enough information to predict the price in the future. Supply interruptions can be incorporated by using a dummy variable. It is worth mentioning that the supply interruption may not have an intermediate effect on the current price. It will, however, have lagged impact. This can be done by putting a lagged dummy variable into the model.

The model is specified as follows:

$$P_t = f(\mathbf{P}_{t-}, \mathbf{D}_t) \qquad (4\text{-}4)$$

where

P_t is the price at time t ;

$\mathbf{P}_{t-}$ is the vector of lagged prices ; and

$\mathbf{D}_t$ is the vector of the lagged dummy variable D, where D is define as:

$$D_t = \begin{cases} 1 & \text{positive jump at time t in OPEC production,} \\ -1 & \text{negative jump at time t in OPEC production,} \\ 0 & \text{otherwise.} \end{cases}$$

A special version of the above model is estimated for the Brent, OPEC spot and WTI prices:

$$B_t = \alpha_{b0} + \Sigma_i^6 \beta_{bi} B_{t-i} + \gamma_{b0} D + \Sigma_j^6 \gamma_{bj} D_{t-j} + \epsilon_{bt} \qquad (4\text{-}5),$$

$$P_t = \alpha_{p0} + \Sigma_i^6 \beta_{pi} P_{t-i} + \gamma_{p0} D + \Sigma_j^6 \gamma_{pj} D_{t-j} + \epsilon_{pt} \qquad (4\text{-}6),$$

$$W_t = \alpha_{w0} + \Sigma_i^6 \beta_{wi} W_{t-i} + \gamma_{w0} D + \Sigma_j^6 \gamma_{wj} D_{t-j} + \epsilon_{wt} \qquad (4\text{-}7).$$

The results are presented in Table 4-8. From the table, we obtain the following points. First, the constant terms are all significant at the 95 percent confidence level and positive, which suggests that the prices have a tendency to increase. Second, information of the prices in period t-1 is very useful to the prices at time t. All the estimates are statistically significant at 99 per cent confidence level. They are all positive, too. This implies that if the prices in t-1 are high, the prices in t are going to be high, too. The prices in t-2, t-3, t-4, t-5, and t-6 are not informative to the prices at time t. This tells us that the crude oil prices have a short memory. Third, the supply interruption dummy does not play any role in the WTI price. However, for Brent price, D_{t-2}, D_{t-3}, D_{t-5}, and D_{t-6} are statistically significant at 90 per cent confidence level. Similarly, supply interruptions had an impact on the prices one, two, three, five and six months later.

Summary

In this chapter, the relationship between crude oil prices and OPEC production has been investigated. The hypothesis that the prices and the production are co-integrated is rejected. A "self-adaptive" model with a supply interruptions dummy is introduced to examine the price behavior. It is found that the 1 period lagged prices had a strong impact on the current prices and the supply

interruptions did have impacts on the prices. However, such impacts were not intermediate as it took about from two to six months for the prices to reflect the interruptions in production.

Table 4-1

Selected Statistics for OPEC Crude Oil Supply and the Prices

Series	Mean	S.D.	Max.	Min.
Supply	18.15	2.08	27.46	14.20
Prices				
Brent	18.69	5.13	29.83	9.51
OPEC	17.46	5.28	37.27	9.72
WTI	19.41	4.94	27.27	8.72

Table 4-2

Cross-Correlations for the OPEC Crude Oil Supply and Price

Variable	Supply	Brent	OPEC	WTI
Supply	1.00	-0.54	-0.59	-0.46
Prices				
Brent		1.00	0.99	0.98
OPEC			1.00	0.97
WTI				1.00

Table 4-3

Selected Statistics for OPEC Crude
Oil Supply and Price Ratios

Ratio to Supply:	Mean	S.D.	Max.	Min.
Prices				
Brent	1.06	0.39	1.90	0.48
OPEC	1.00	0.40	1.83	0.44
WTI	1.10	0.38	1.92	0.58

Table 4-4

Regression Coefficients for Crude Oil Prices on the OPEC Supply

Variable	Dependent variable		
	Brent	OPEC	WTI
Constant	42.87* (8.49)	44.64* (8.95)	39.35* (7.68)
S	-1.33* (-4.82)	-1.50* (-5.48)	-1.10* (-3.92)
1st-Order Autocorrelaton	0.88	0.88	0.86
R^2	0.29	0.35	0.22
$\overline{R}^2$	0.28	0.35	0.22
D-W	0.20	0.34	0.20
Std. Error	4.35	4.30	4.41

Table 4-5

Results of Integration Tests for OPEC Crude Oil Supply and the Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
S	0.231	-1.64	-1.76
Brent	0.100	-1.75	-2.35
Spot	0.050	-1.37	-1.44
WTI	0.147	-1.74	-2.63

Table 4-6

Results of Integration Tests for First Order Differenced OPEC Crude Oil Supply and Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
Δ S	1.72	-6.90	-5.73
Δ Brent	1.27	-5.05	-3.13
Δ Spot	1.13	-4.99	-4.64
Δ WTI	1.45	-5.60	-4.13

Table 4-7

Results of Cointegration Tests for OPEC
Crude Oil Supply and Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 95%: -3.17)
Case 1	0.08	-1.75	-2.11
Case 2	0.07	-1.82	-2.06
Case 3	0.11	-1.67	-2.33

Key:

Case 1: OPEC Oil Supply Price vs Brent Price
Case 2: OPEC Oil Supply Price vs Spot Price
Case 3: OPEC Oil Supply Price vs WTI Price

Table 4-8

"Self-Adaptive" Model for Crude Oil Prices

Independent	Dependent Variable		
	B_t	P_t	W_t
Constant	4.07 (2.12)	3.53 (2.18)	4.70 (2.06)
t-1	0.81 (4.30)	0.92 (4.96)	0.76 (4.00)
t-2	-0.08 (-.34)	-0.15 (-.59)	0.13 (0.54)
t-3	0.38 (1.81)	0.36 (1.63)	0.12 (0.54)
t-4	-0.17 (-.81)	-0.18 (-.78)	-0.11 (-.50)
t-5	-0.09 (-.41)	-0.13 (-.57)	0.01 (0.05)
t-6	-0.08 (-.55)	-0.06 (-.40)	-0.17 (-1.10)
D_t	0.39 (0.82)	0.57 (1.35)	0.24 (0.42)
D_{t-1}	0.85 (1.46)	0.99 (1.85)	0.84 (1.22)
D_{t-2}	1.00 (1.71)	0.87 (1.65)	0.55 (0.80)
D_{t-3}	1.00 (1.68)	0.98 (1.87)	0.12 (0.12)
D_{t-4}	0.32 (0.57)	0.17 (0.34)	0.18 (0.27)

Table 4-8--Continued

D_{t-5}	0.85 (1.66)	0.84 (1.81)	0.47 (0.73)
D_{t-6}	0.72 (1.59)	0.69 (1.65)	0.55 (1.00)
R^2	0.83	0.86	0.77
$\overline{R}^2$	0.74	0.80	0.65
DW	1.84	1.79	1.89
S.E.	1.17	1.04	1.40

CHAPTER V
CONCLUSIONS

This dissertation concentrates on the crude oil markets, both spot and futures, and examines the relationship between the two markets. Three pairs of relationships, the OPEC spot price and the futures prices, the futures prices and the OPEC oil production and the spot prices and OPEC production, have been examined in this paper. Some important conclusions obtained are as follows.

First, in this dissertation, I proposes a two stage testing procedure for determining the long-run relationship between two time series. First, it should ensure the existence of the relationship. Second, only after the relationship is established, can the relationship itself be studied. Most of the literature on studying the relationship between the futures market and spot market has ignored the first step. The relationship is assumed to exist without testing. This assumption, however, can be wrong, because such a relationship may not exist at all. Chapter Three provides a very good illustration of this.

Second, the spot price and 1-month-ahead futures price are found to be co-integrated, which suggests that there is a stable long-run relationship between them. Therefore, the

first step of the "two-stage" testing procedure is satisfied. We can go to the second step which is to study the relationship itself. The important thing about the relationship is to check the causality direction. By using two methods, the Garbade and Silber approach and Granger causality test, it has been found that the spot price always leads the futures price. The quantitative analysis is then followed by implementing an error correction model. The model, once again, reveals that the spot price provides information for the futures prices, but not vise verse.

Third, the relationship between the futures prices and OPEC oil production was investigated. It was found that they were not co-integrated. However, to show the mistake made by most of the researchers in this area that ignore this fact, the relationship was nonetheless studied with the Garbade and Silber approach and the Granger causality test. The results, not surprisingly, were contradictory.

Fourth, the spot prices and OPEC production are found not to be co-integrated. Therefore, the production variable should not be included in the model to study the prices. A "self-adaptive" model with a supply interruption dummy has been proposed and the results are convincing.

APPENDIX ONE

Integration and Co-integration Test of the OPEC Crude Oil Production and Prices with the Sample 1986 - 1989

Since the period from January to December in 1985 seems to be an "outlier", we deleted these observations and implemented the integration and co-integration tests for the OPEC oil production and prices by using this reduced sample. Table A-1 and A-2 represent the integration test results and Table A-3 depicts the co-integration test.

Table A-1

Results of Integration Tests for OPEC Crude Oil Supply and the Prices, 1986 - 1989.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
S	0.244	-1.07	-1.29
Brent	0.394	-2.86	-1.81
Spot	0.365	-3.25	-2.03
WTI	0.478	-2.94	-1.84

Table A-2

Results of Integration Tests for First Order Differenced OPEC Crude Oil Supply and Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 99%: -3.77)
Δ S	1.58	-5.62	-4.79
Δ Brent	1.43	-6.19	-4.61
Δ Spot	1.18	-5.88	-4.52
Δ WTI	1.43	-7.53	-5.04

From Table A-1 and A-2, it is clear that the levels of the all variable are not stable too in this sample as well. From Table A-3, we can see that even the results are improved with this sample since all the statistics are larger than those with the old sample, however, they are still not significant. Therefore, the OPEC oil production and the prices are not co-integrated in this sample, too.

Table A-3

Results of Cointegration Tests for OPEC Crude Oil Supply and Prices.

Series	CRDW (crit. value 99%: 0.532)	DF (crit. value 99%: -4.07)	ADF (crit. value 95%: -3.17)
Case 1	0.37	-2.76	-2.16
Case 2	0.32	-2.86	-2.16
Case 3	0.44	-2.93	-2.06

Key:

Case 1: OPEC Oil Supply Price vs Brent Price
Case 2: OPEC Oil Supply Price vs Spot Price
Case 3: OPEC Oil Supply Price vs WTI Price

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BIOGRAPHICAL SKETCH

Quan, Jing was born in Zhushang, a small town in Northwest China, on the 22nd of April, 1963.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholar presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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